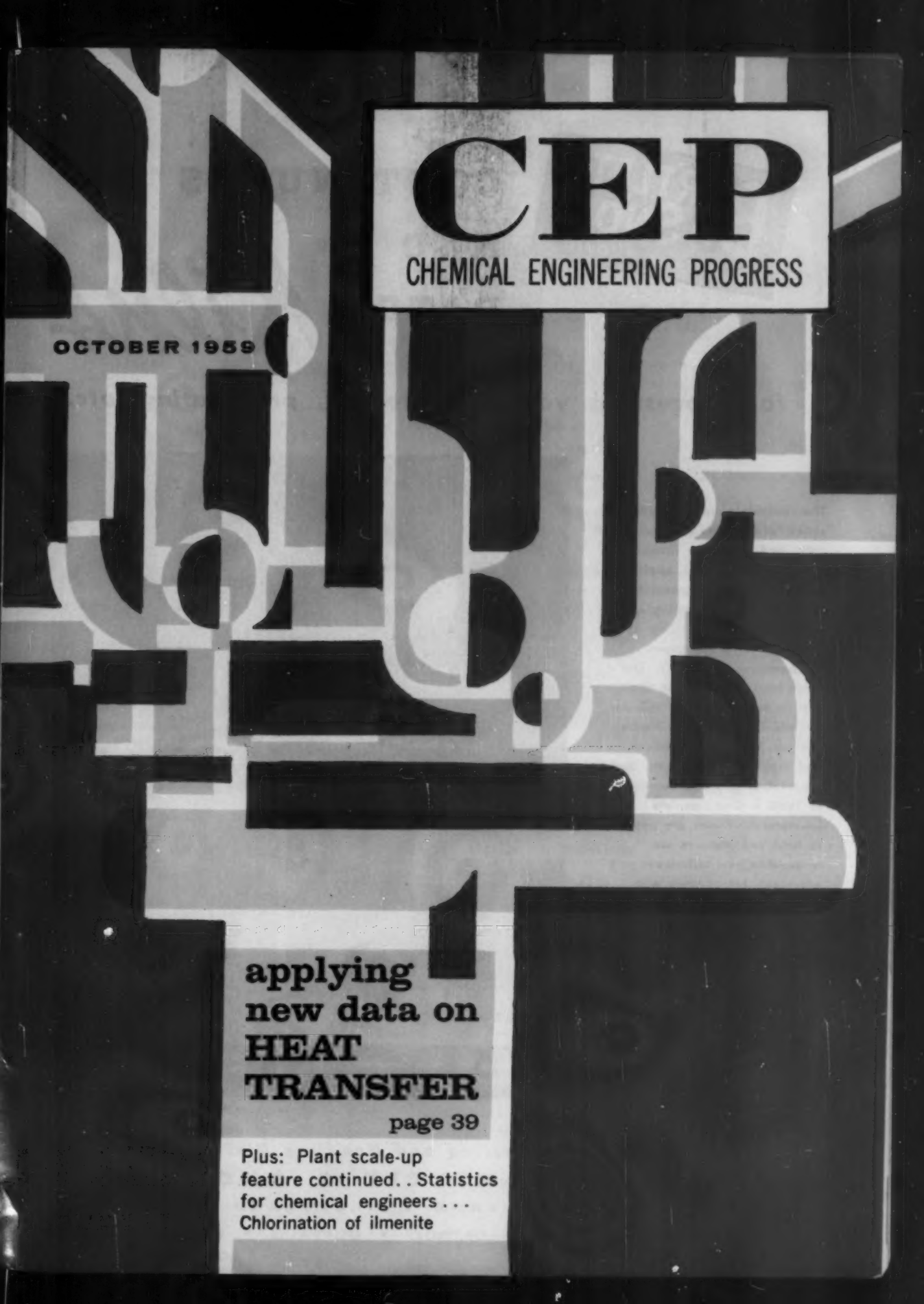
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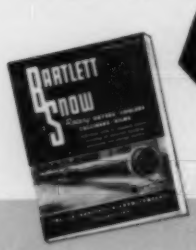

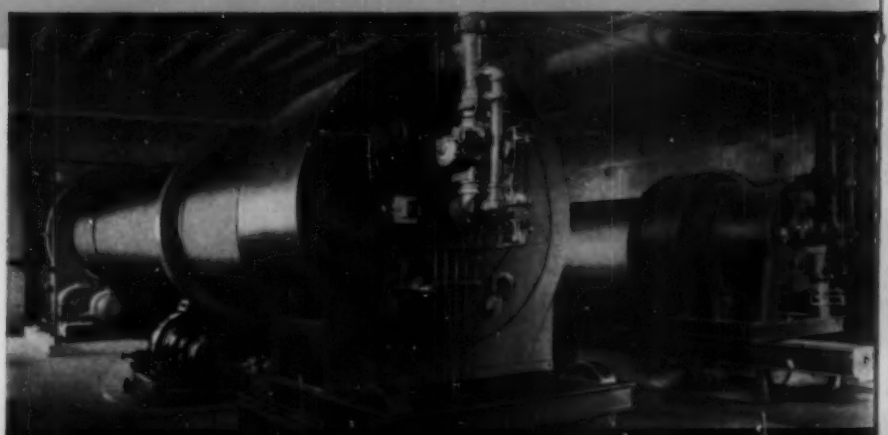

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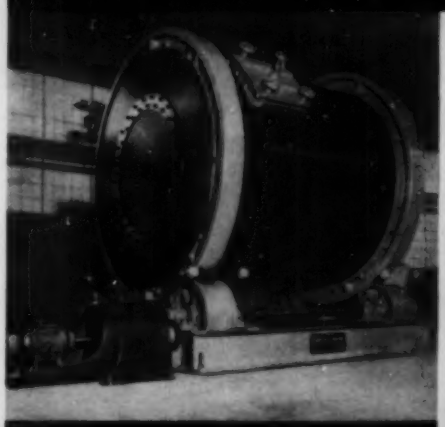

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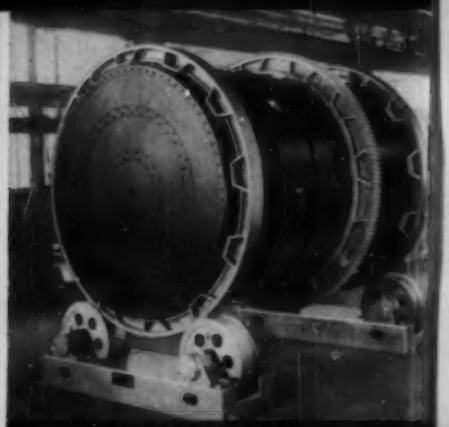

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12 and heavier	12½% of wall	.005 sq. inches

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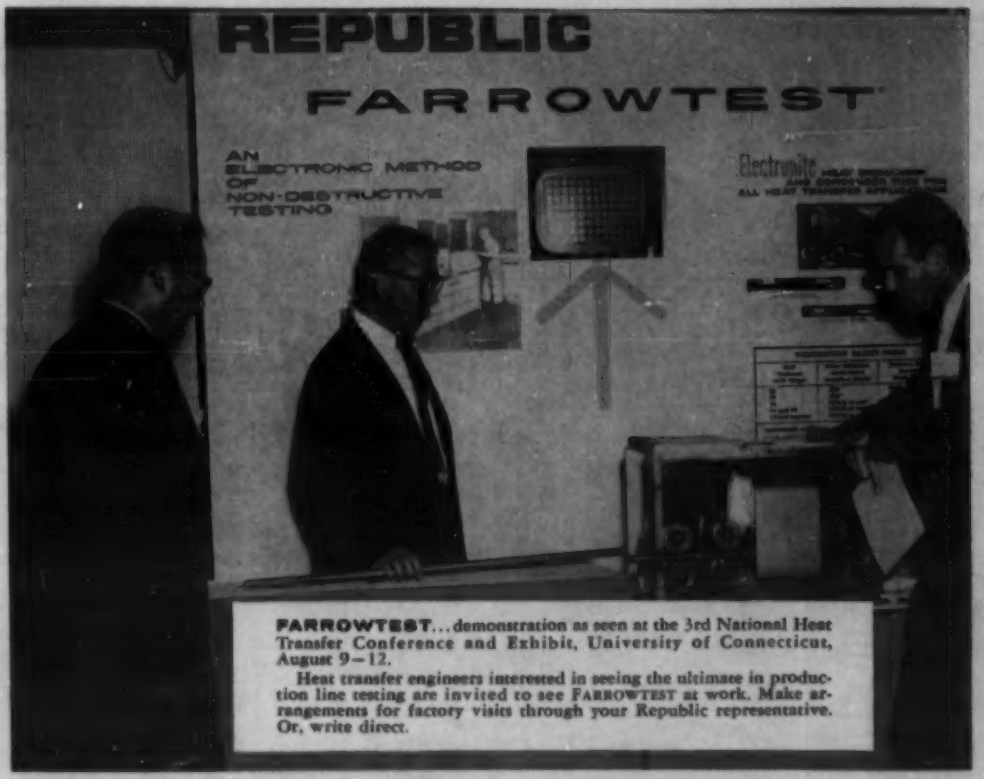

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On academic titles, metric system

The A.I.Ch.E. South Texas Section opinion survey (*CEP*, July 1959, pp. 73-5) indicates considerable opposition to the wider use of academic titles. Use of titles is one way of reminding the public that scientists and engineers are university-trained professionals like physicians, lawyers, etc., hence this opposition is disappointing. It also appears paradoxical, since survey respondents seem dissatisfied with their professional status, and with Institute efforts to improve it (cf. response to Questions 8, 9, and 14, Table 2-B).

Last year I proposed the use of titles in journals of the American Chemical Society (*Chem. Eng. News*, Feb. 3, 1958, p.15; *ibid.*, Sept. 29, 1958, pp.80-1), for increasing the prestige of our profession. The ACS Council voted to recommend to the Board of Directors adoption of such policy (*ibid.*, Oct. 27, 1958, p.73). Data from an ACS author survey, and the A.I.Ch.E. data compare as follows:

	No. of respondents	% for titles	% against titles
ACS	416	60.0	40.0
A.I.Ch.E.	490	29.4	60.8

Details from the ACS opinion survey follow:

Respondents	No. for titles	No. against titles
with doctorates	198	109
without doctorates	52	57
younger than 40	160	87
over 40	90	79
in industry	124	63
elsewhere	126	103

(data from ACS Council Committee on Publications—Serial Memo 1, Feb. 1959). Granting that the ACS and A.I.Ch.E. samples differ in several important respects, I believe the main difference is that ACS members had given the matter more thought by discussing it for quite some time.

Proposals I submitted to A.I.Ch.E. and other engineering societies for the use of titles in publications were referred to the Engineers' Council for Professional Development whose Committee on Recognition has placed the matter on its agenda. The eventual outcome, both in the ACS and ECPD, is bound to depend largely on how the members feel. The above is written in the hope that A.I.Ch.E. members will give the use of titles serious consideration, and voice their thoughts on this proposal.

Peter D. Moskovits, M.S., Chem.E.
Rahway, New Jersey

Metric system

I recommend that you reprint F. W. Hough's "Metric System in the U.S.A."? which appeared on page 122 of the April issue of *Mechanical Engineering*.

A gradual conversion to the metric system as proposed by Hough is a project which the A.I.Ch.E. and each of its members should enthusiastically support. Such a conversion may well become an economic necessity in the years ahead as foreign competition with U.S. industry, both in world and domestic markets, continues to increase.

David D. Bockman

Seattle,
Washington

Agreeing with Mr. Bockman on the importance of the question of metrics or not-metrics, CEP is pleased to reprint the letter from Hough which appeared in Mechanical Engineering *—Ed.*

Metric System in U.S.A.?

Pursuant to the resolution adopted unanimously at the business session of the American Geophysical Union, on May 7, 1958 (*AGU Transactions*, June, 1958, p. 558), President Maurice Ewing appointed a "Committee on Adoption of the Metric System in the United States."

Bills for the compulsory adoption of the metric system in the United States have been more than once presented to Congress, but they failed, the principal reason being that the effective date proposed was entirely too soon after passage of the bill. An early effective date would undoubtedly work a severe hardship on the adult population not familiar with the metric system, and it would make obsolete a prohibitive amount of everyday items of weights and measures. A solution would appear to be a bill to make the metric system the only official system of weights and measures in the United States, effective in not less than one generation, 33 years, after passage of the bill. Following this action by the Congress, the grade schools and high schols could begin immediately to teach children the metric along with the English system and, during the transition period, could place more and more emphasis on the metric system. By the end of the transition period, the English System could still be taught, but the emphasis would be completely reversed from what it is today.

A long transition would result in a smooth change. In a generation, most items of equipment involving weights and measures normally become obsolete or worn out and replaced. Also, persons engaged in professions and trades now using the English System exclusively would normally pass on to retirement during this period and would be replaced by a new generation thoroughly educated and trained in the metric system.

A questionnaire has been prepared for the purpose of gathering statistical information to indicate the degree of interest in this matter.

Copies of the questionnaire are available upon request addressed to: The Executive Secretary, American Geophysical Union, 1515 Massachusetts Avenue, N.W., Washington 5, D. C. A small effort on the part of interested parties to complete and mail this questionnaire will be of invaluable help to the Committee.

Floyd W. Hough

Chairman, Committee for the Study of the Metric System in the United States, American Geophysical Union, Washington, D. C.

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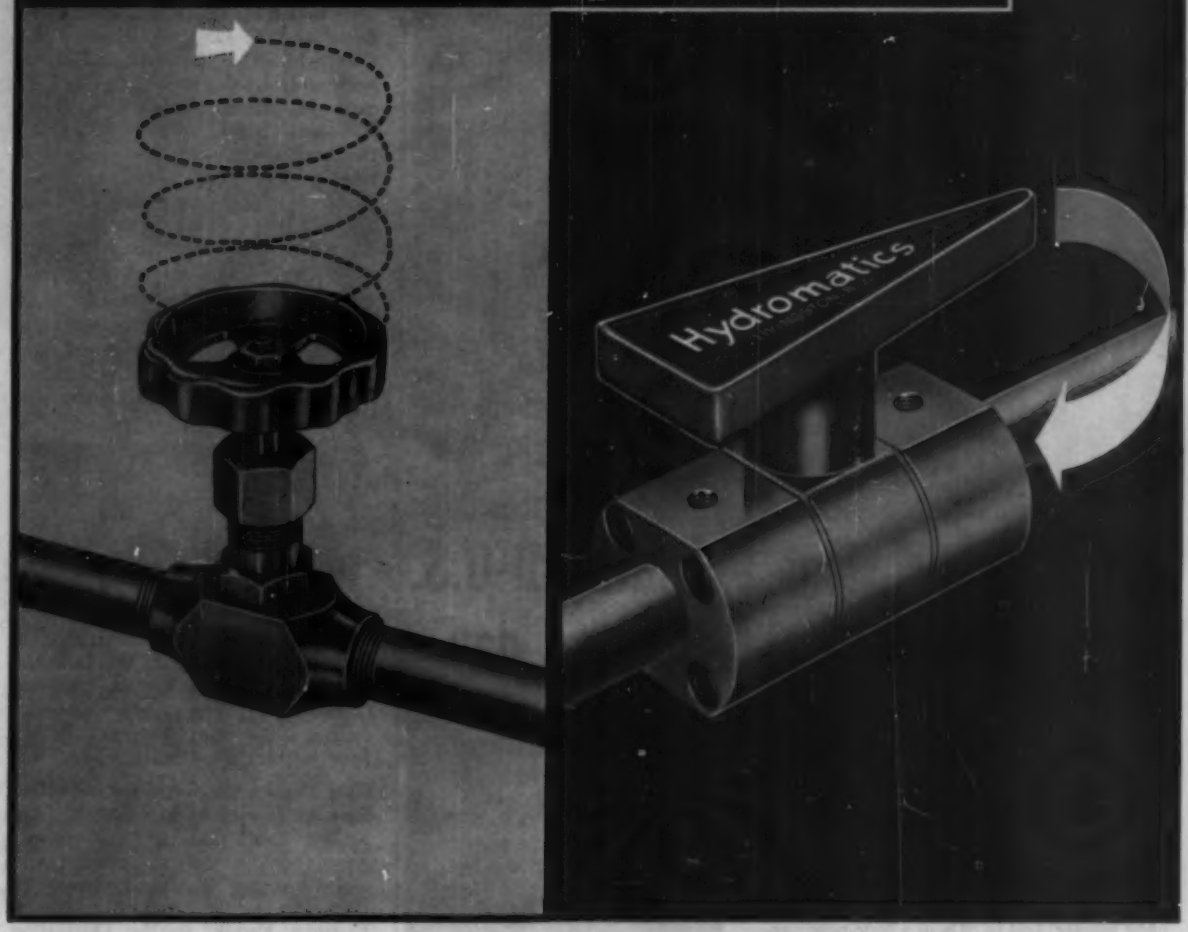

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about our authors

Heat and Mass Transfer Analogy is the result of collaboration between five men. **H. Z. Hurlburt, D. R. Brake and E. G. Lang** directed the tests, while **J. F. Revilock** and **D. Q. Kern** correlated results. Revilock is manager, process equipment sales, at National Carbon, Cleveland, Ohio. Hurlburt is director of research at Stauffer Chemical, Houston, Texas. Brake is plant engineer, and Lang assistant plant supervisor, at the same plant. Kern of D. Q. Kern Associates, is well known to the readers of CEP.

J. J. Taborek (*Organization of Heat Exchangers on Digital Computers*) is in charge of the computer program developments for process equipment design, Phillips Petroleum, Bartlesville,

Revilock Jen Su Ryan

Oklahoma. Taborek, who studied in Europe, has a degree in ME from the Institute of Technology in Dresden, Germany, and also taught thermodynamics at the same University. He has been in the United States since 1955.

Gary Brooks and **Gouq Jen Su** (*Heat Transfer in Baffled Jacketed Agitated Kettles*) both hail from Rochester, New York. Su is on the chemical engineering staff of the University of Rochester, while Brooks works with Eastman Kodak, in the Distillation Development Laboratory.

Some of the interest in results of the study *Effect of Gas Evolution on Heat Transfer*, arises from the enhanced rates of heat transfer. However, **K. O. Beatty** points out, this was not a gadgeteering project, but merely part of the results of a much larger

Chon Mixon Zimmerman

fundamental research program. Beatty is acting head of the Department of Chemical Engineering at the University of North Carolina. **F. O. Mixon,**

continued on page 12

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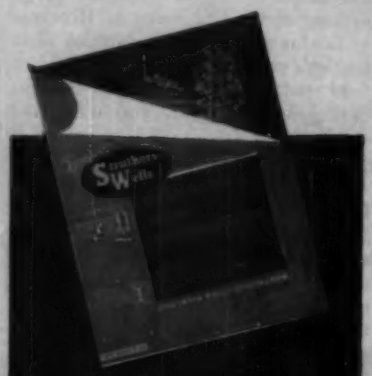

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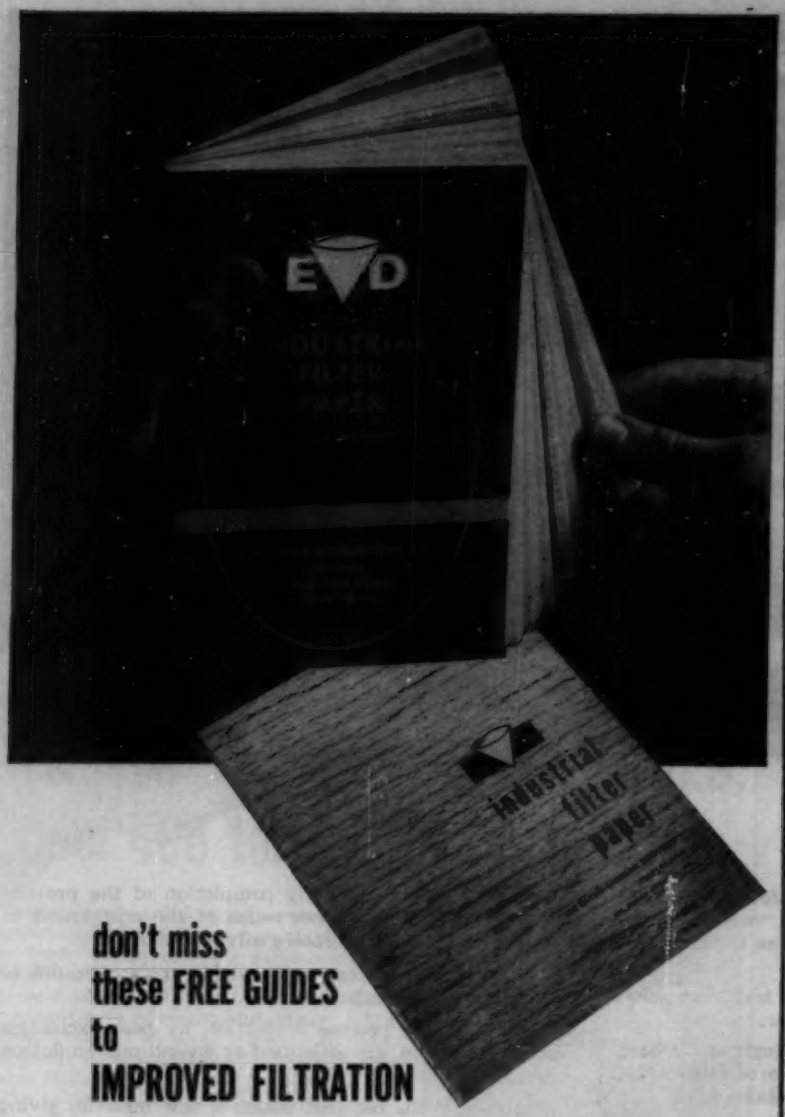

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about our authors

from page 10

Jr. and **Wan Yong Chon** worked under him on the problem.

Chon was taught electrochemistry at Seoul National University, and held a teaching fellowship at the University of Michigan. He is with Atomic Power Development Associates, Detroit, Michigan, and also finishing work on his doctorate. Mixon has completed his formal studies and is a research engineer in the Du Pont lab at Wilmington, Delaware. Beatty has published many papers on heat transfer, fluid flow, and smoke measurements. His present activities include a continuation of the work in boiling mechanism.

Another happy result of collaboration between teacher and student is *Populations of Active Sites in Nucleate Boiling Heat Transfer*. **Richard F.**

Koehler Duckler Taborek

Gaertner's Ph. D. thesis, the work was conducted under **J. W. Westwater** at the University of Illinois, where he is a member of the chemical engineering Department. Gaertner is now in the research lab of General Electric, Schenectady, New York.

A. E. Dukler (*Fluid Mechanics and Heat Transfer in Vertical Falling Film*) is active both in the academic and commercial fields. A member of the Department of Chemical Engineering at the University of Houston, he is also with a local consulting firm. Dukler's research takes in the field of fluid mechanics, and heat transfer during multiphase flow and in the area distillation.

A. D. Ryon, F. L. Daley, and **R. S. Lowrie,** authors of *Scale-up of Mixer Settlers* feel that the principles involved, in addition to proven usefulness in design of solvent extraction in uranium mills, should have application in the general field of solvent extraction. Ryon has done much work in research and development on metals separation techniques for materials involved in reactors, mainly solvent extraction, ion exchange and precipita-

continued on page 30

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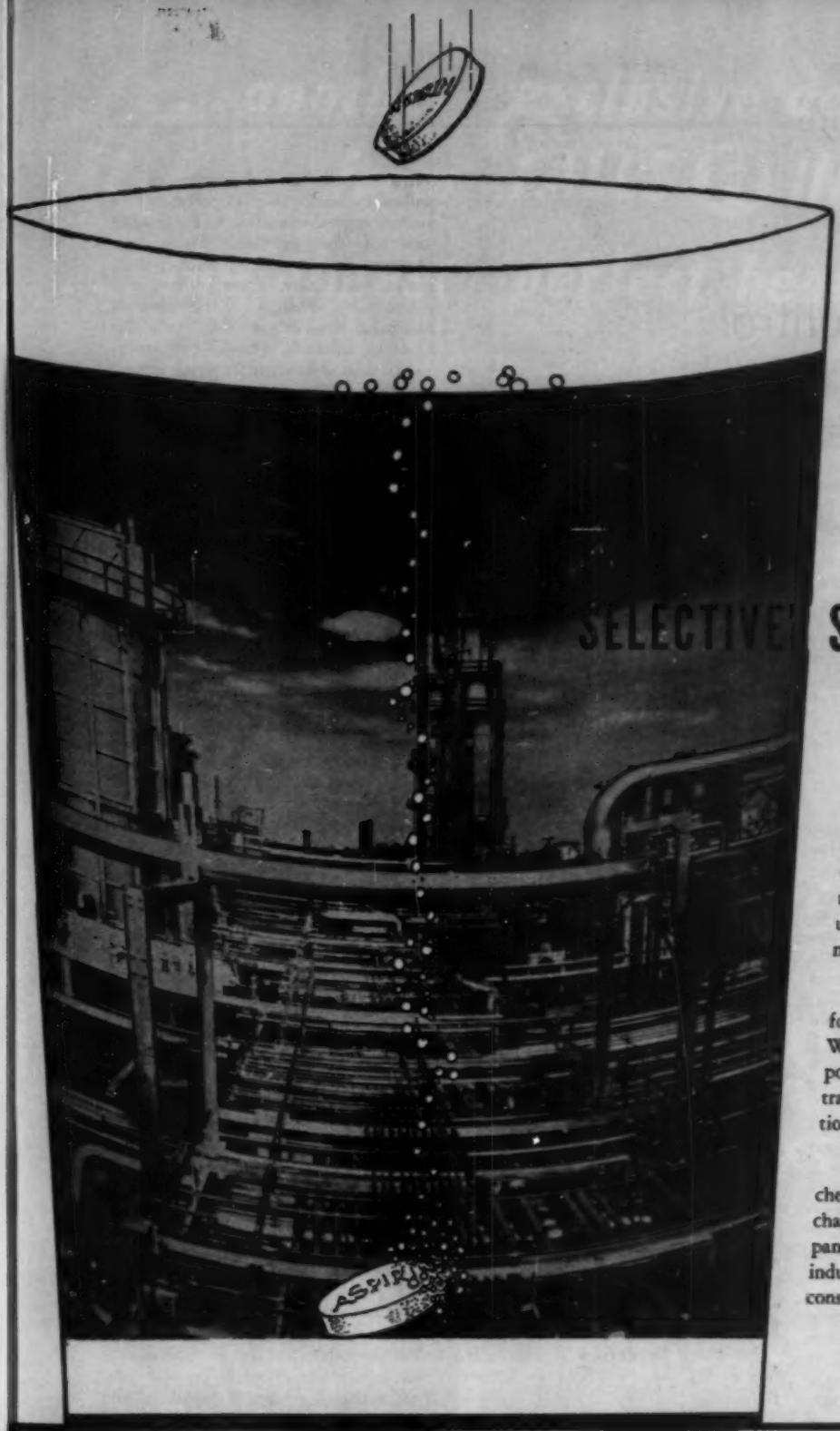

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Heat transfer, air pollution control

1959 Heat Transfer and Fluid Mechanics Institute Preprints of Papers, Stanford University Press, 243 pp., $7.50.

Reviewed by P. K. Baumgarten, research engineer, Engineering Dept., Wilmington, Delaware.

The eighteen papers in this collection deal chiefly with nose cone and satellite problems, and with the flow of electrically conducting fluids in a magnetic field. Extreme conditions prevail: hypersonic speed at Mach 10; rarified atmospheres so thin that the molecules collide oftener with a speeding satellite than with each other; nose cones brightened to incandescence by aerodynamic friction; ionic and electronic plasmas in magnetic fields, hinting at future development of controlled hydrogen fusion. The chemical engineer reading these papers stumbles on unfamiliar terms such as "Hartmann number", "ablation" and "shock within shock" before getting his bearings.

The titles of the five sections of this volume indicate the scope of the papers: (1) Rarified Gas Flows (2 papers), (2) Magnetohydrodynamics (4 papers), (3) Fluid Mechanics and Heat Transfer (4 papers, chiefly dealing with nose cone problems), (4) Ablation, Mass Transfer, and Separation (4 papers, again chiefly on nose cone or satellite problems), and (5) Novel Techniques and Ideas (4 papers on thermodynamic properties and interaction between electrical fields and supersonic streams). None of these papers deal with fluid flow and heat transfer in the sense that we may be most familiar with. Only occasionally do we find references to flow in pipes or correlations in terms of Nusselt and Reynolds number. Most of the heat transfer papers of interest to us earth-bound engineers were probably sent this year to the recent A.I.Ch.E.-A.S.M.E. 3rd Annual Heat Transfer Conference at Storrs, Connecticut.

Three papers may be mentioned in more detail. In a discussion of shock tube measurements, R. W. Rotowski deals with stagnation point heat transfer in a partially ionized gas. He uses an enthalpy gradient as the driving force for heat flux in a case which is analogous to the heat transfer from a dissociating gas. This subject has been treated recently in the chemical engineering literature. In another paper, S. Globe reports on the application of an axial magnetic field to the flow of mercury in a pipe. The field resulted in the suppression of turbulence and increased the transition Reynolds number from 2000 to as high as 3800. An interesting method of surface temperature measurement was reported by O. K. Tewfik and W. H. Giedt. Local temperature was indicated by the resistance of a painted-on film of platinum. The electrical leads were connected to this film by painted strips of silver.

The contents of this volume indicated that great strides are being made in attacking the heat transfer and fluid mechanics problems of the space engineer. Whether a chemical engineer will find interest in this collection will depend on his ability and willingness to translate the subject matter to his own field.

Air Pollution Control, W. L. Faith, John Wiley and Sons, Inc., New York, N. Y., (1959), 259 p., $8.50.

Reviewed by Vernon T. Stach, Jr., Roy F. Weston, Inc., Newton Square, Pa.

This book provides an introduction to air pollution which can be enjoyed by anyone with a technical education. A familiarity of the reader with specialized air pollution terms is not assumed.

The problem is first defined in terms of the several effects of air pollution and the importance of meteorological condition in the magnitude of the problem. Succeeding chapters are devoted to smoke; dust, fumes, and mists; gases; odors; and automobile exhausts. Each chapter discusses sources of the particular problem, methods of making measurements, and abatement equipment and techniques. The last two chapters are devoted to air pollution surveys and the legal aspect of air pollution control.

This book is an excellent first introduction to the general problem of air pollution. Each chapter is well referenced, which supplies added value as a starting point for literature searches.

Fine Particle Measurement, Size, Surface and Pore Volume, Clyde Orr, Jr. and J. M. Dallavalle, The Macmillan Company, New York, N. Y., (1959) 353 pp., $10.50.

Reviewed by T. D. Heath, Ass't. Director of Westport Laboratories, Dorr-Oliver, Inc.

This book is the most complete single volume now available on particle measurement. It is recommended for all engineers who have problems in measuring the size, surface, or the pore volume of fine particles.

The book is well organized. The first chapter (12 pages) is designed to put the reader on a good operating foundation. It presents basic definitions, rules for selecting methods of measurement, and some fundamentals of particle size distribution. The next four chapters (120 pages) are devoted to the measurement of particle size by (1) microscopy and sieving, (2) sedimentation, (3) inertial techniques, and (4) radiation scattering and transmission. The following four chapters (123 pages) present the measurement of surface area by (1) permeametry, (2) gas adsorption, (3) liquid-phase sorption, and (4) miscellaneous methods. The last chapter (13 pages) discusses the measurement of pore size and pore-size distribution.

A desirable feature of the book is the separation of each chapter into two sections wherever possible; one section being on Theory and the other on Methods. Despite this separation, the book is more a textbook on particle size measurement than it is a manual of methods and operating procedures. Basically the book provides the reader

continued on page 16

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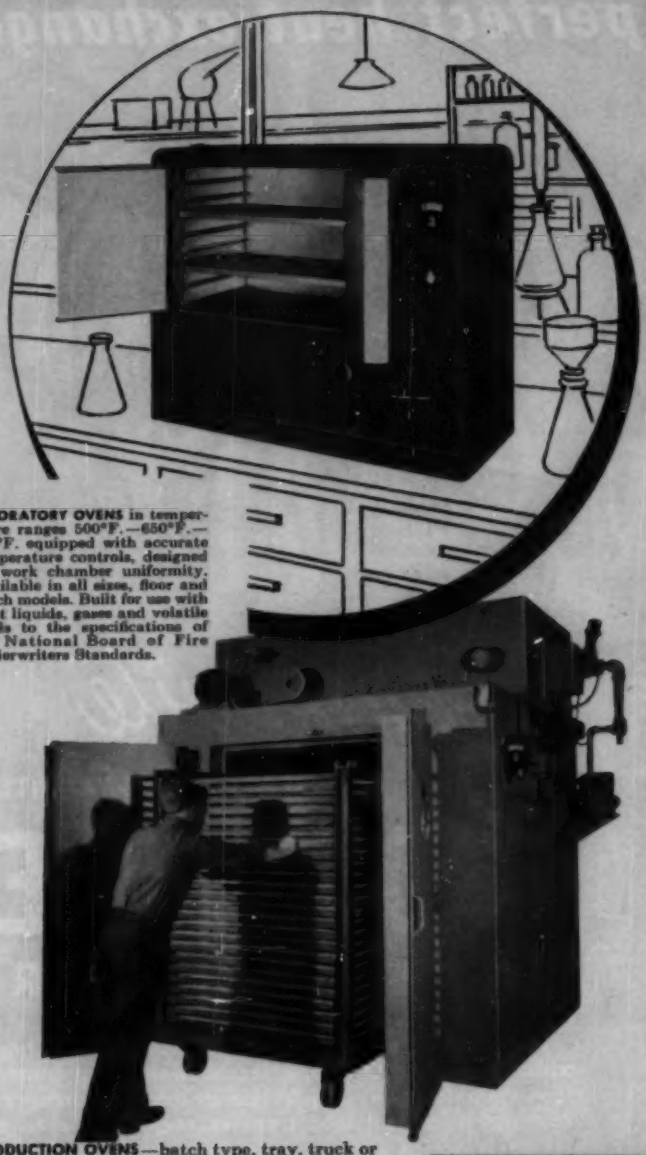

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marginal notes

from page 14

with a good background in the fundamentals of particle measurements. An excellent bibliography (625 references) is included to facilitate detailed study of particular techniques.

Faults of the book are only those of omission, and these can easily be corrected in a future edition. The book is not a handy reference book for rapid evaluation of particular techniques or methods. The subject index of the book is woefully incomplete so that it is difficult to find subjects of special interest. The Coulter Counter, for example, which is described in an unexpected section of the book, is not listed in the subject index. Several size analysis methods including the Haultain Infrasizer, the Bahco Centrifugal Classifier, and the Sedimentation - Decantation Technique have been omitted. Many readers will wish for more detailed evaluation of commercially available apparatus such as the Sharples Micromerograph and the Coulter Counter.

Despite its few faults, this book will be a welcome addition to the library of an engineer or company to whom particle measurement is a recurring problem.

WELDING OF PLASTICS, J. Alex Neumann and Frank J. Bockhoff, Reinhold Publishing Corp., New York, N. Y., 279 pages, $7.25.

Reviewed by F. X. Gigliotti, Monsanto Chemical Company, Plastics Division, Springfield Mass.

The use of an engineering material of construction is highly dependent upon the ease and techniques of fabrication. Among the most important of these techniques is the method of joining.

This book is a comprehensive treatise of the welding method of joining products made from thermoplastic materials with particular emphasis upon design and shop practices.

Based to a large extent upon European experience, particularly with polyvinylchloride and polyethlene, the specific details of sound practice are outlined and illustrated for hot-gas, heated-tool, and friction welding. As the authors observe, the welding of thermoplastics has much in common with the welding of metals, and a natural extension of theory and practice (including such prosaic items as symbols) is in order.

Chemical engineers, particularly those involved in the design and fabrication of specialized corrosion resistant equipment, will find this book helpful.

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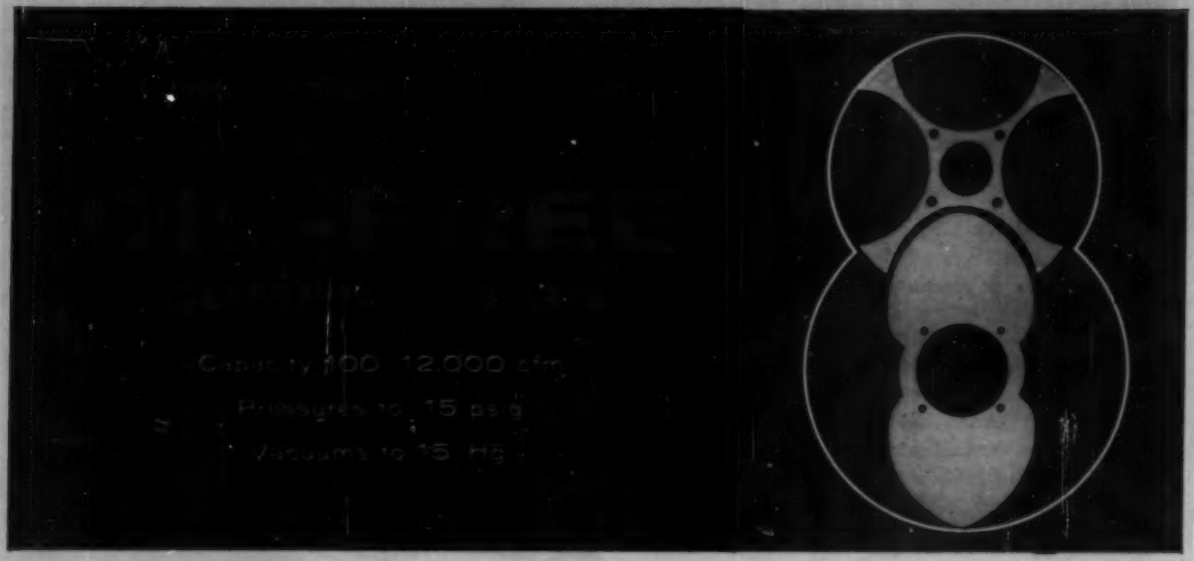

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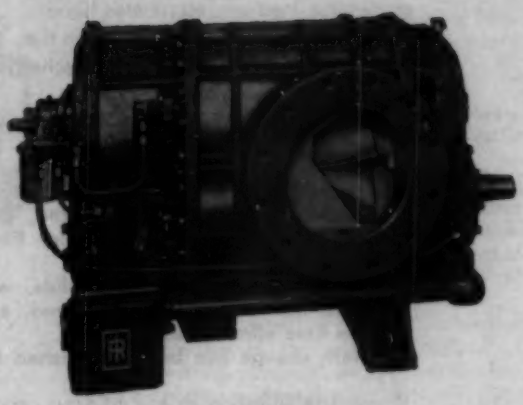

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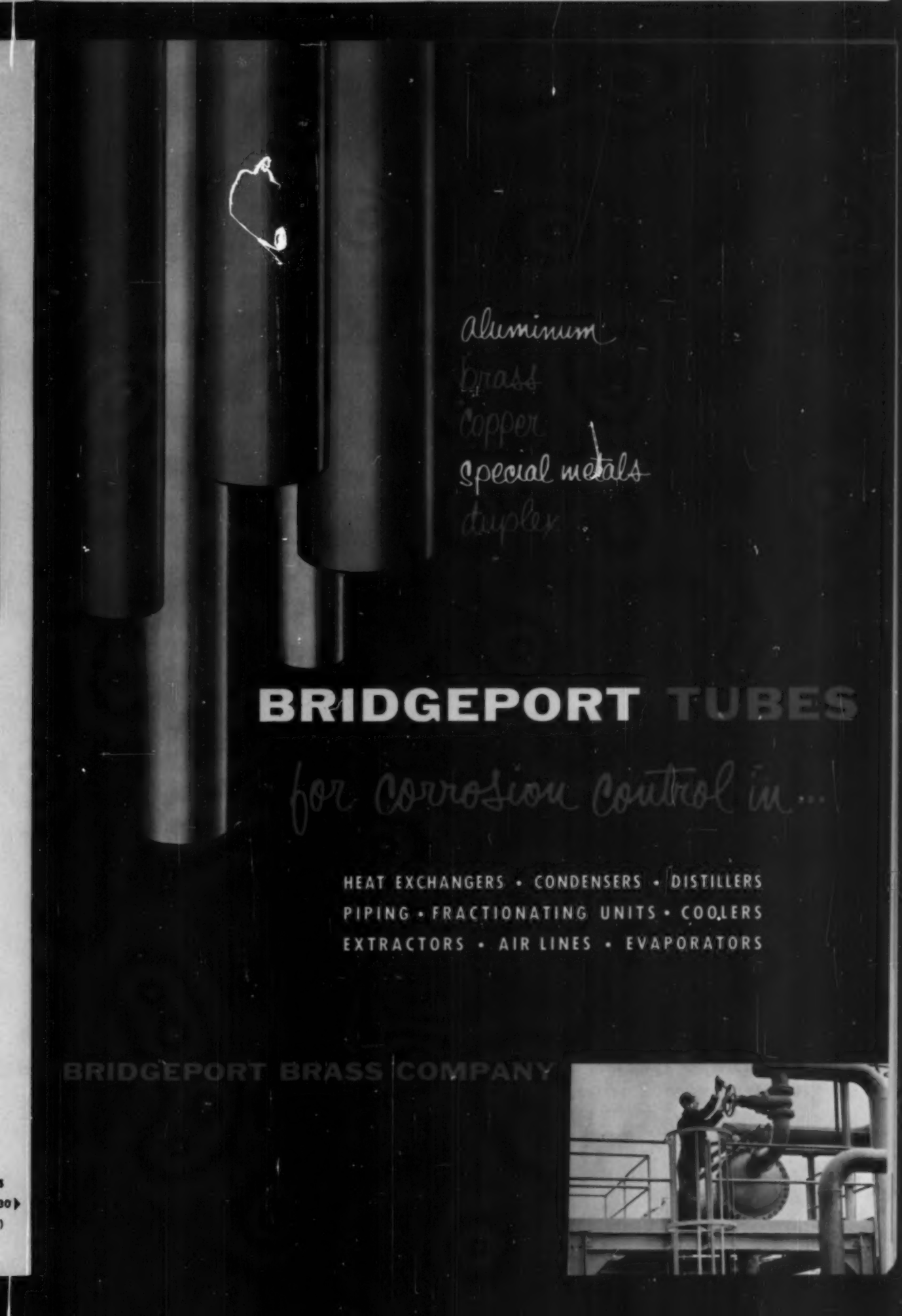
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Deoxidized Arsenical Copper 108 (Copper and arsenic.)
Suitable for handling fresh waters. Heat resistance 150°C higher than electrolytic copper. Applicable to feed water heaters, fresh water condensers, chemical manufacture, meat packing, sugar refining and food processing.

Inhibited Aluminum Bronze 53 (Copper, aluminum and arsenic.)
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Muntz Metal 141 (Copper and zinc.)
Handles inland fresh waters. Shows less resistance to dezincification than Arsenical Muntz 142, other properties are similar.

Red Brass 85 (Copper and zinc.)
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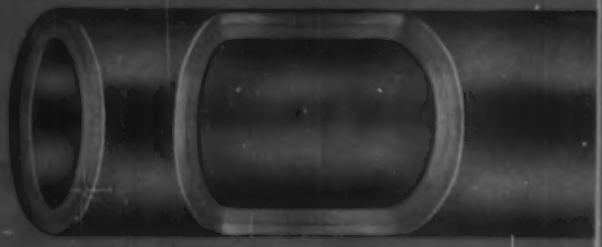

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			Outside Metal	Inside Metal
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Amine coolers	Amine	Salt water	Steel or Aluminum	70-30 Cupro Nickel
Ammonia condenser	Ammonia gas or liquid	Sea water and fresh water	Low Carbon Steel	Copper or Copper Alloys
Ammonia manufacture	Fresh water	Ammonia liquid and gas	Copper or Copper Alloys	Steel
Ammonia refrigeration	Ammonia	Fresh water and sea water	Steel	Copper or Copper Alloys
Benzol condenser	Benzol vapors	Sea water	Low Carbon Steel	Admiralty
Benzol cooler	Benzol liquid	Sea water	Low Carbon Steel	Admiralty
Brine cooler	Brine	Sea water	Low Carbon Steel	Cupro Nickel
Carbon dioxide manufacture	Carbon Dioxide absorbent	Cooling water	Low Carbon Steel	Copper
Chemical condenser	Chemical service and nitric acid cleaning	Sea water	304 Stainless Steel	Cupro Nickel
Chemical coolers	Chemical service and nitric acid cleaning	Sea water	304 Stainless Steel	Cupro Nickel
Coke ammonia liquor coolers	Ammonia Liquor and naphthalene	Cooling water	Low Carbon Steel	Copper or Copper Alloys
Edible oil coolers	Edible oil	City water	Low Carbon Steel	Copper
Formaldehyde condenser	Formaldehyde	Fresh water	Aluminum	Copper
Formaldehyde cooler	Fresh water	Formaldehyde	Copper	Aluminum
Formaldehyde condenser	Formaldehyde and formic acid	Cooling water	316 Stainless Steel	Copper or Copper Alloys
Fuel oil heaters	Steam	Fuel oil	Copper	Steel
Gasoline condenser	Gasoline plus hydrogen sulfide	Sea water	Aluminum	Admiralty
High stage gas condenser	Cooling water	Wet gas high in hydrogen sulfide and containing some ammonia	Admiralty	Low Carbon Steel
Hydrocarbon condenser	Hydrocarbon and trace of mercury	Sea water	Low Carbon Steel	Aluminum Brass
Hydrocarbon condenser and cooler	Hydrocarbons and trace of ammonia	Sea water and fresh water	Low Carbon Steel	Admiralty, Copper Alloys
Lube oil cooler	Lubricating oil	Sea water	Aluminum	Duronze IV
Mercury rectifier	Mercury	Cooling water	Low Carbon Steel	Copper
Resin reactors	Resin	Steam or cooling water	Aluminum	Admiralty
Rubber chemicals cooler	Water	Rubber chemicals	Copper	Low Carbon Steel
Rubber chemicals cooler	Water	Rubber chemicals	Copper	Aluminum
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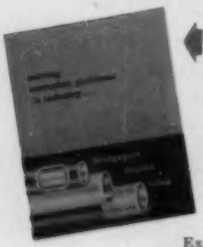

Bridgeport Duplex Tubes — 24 pages. Describes advantages of dual metal tubes and tube sheets in solving difficult corrosion problems involving two corrosive media in heat transfer equipment. Includes design, installation data, table of typical applications.

Condenser & Heat Exchanger Tube Handbook — 162 pages. Covers installation or replacement of Condenser or Heat Exchanger Tubes, helps you select the best alloys for efficient, economical, low maintenance operation.

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SCOPE

Chemical industry research tab seen at $1 billion by 1970

Private chemical research expenditures in the U.S. may well climb up to or even past the $1 billion mark by 1970, said recently J. Peter Grace, president of W. R. Grace, in an article prepared for the Journal of Commerce. In spite of recession troubles in 1958, points out Grace, industrial research expenditures continued to soar. Outlay for 1959 is expected to hit $600 million, an increase of $50 million over 1957, he notes. According to Grace, the prime reason for this increase in research dollars is that the accepted percentage of sales spent for research by the major companies is also increasing. "In some chemical companies," he says, "including our own, the total research budget already exceeds 4% of sales, while some pharmaceutical companies spend as much as 8-10% of sales."

In another trend to be watched for, predicted Grace, chemical companies will extend their basic position in the years just ahead, and will become more like petroleum companies. To even the score, more non-chemical companies will continue to move into chemicals. As examples of the large scale integration, we have only to look at firms such as Phillips Petroleum with its Chemical Division which makes polymers from petroleum by-products, and Esso Standard, which markets chemical specialty products through its subsidiary, Enjay. Monsanto bought Lion Oil in 1955, and has expanded its position in agricultural chemicals, while both Monsanto and Dow have acquired gas and oil reserves to protect their raw material position.

With the trend toward large-scale enterprises in the petroleum and chemical fields, businesses that run into hundreds of millions of dollars before they are off the ground, continued Grace, we should look for more joint ventures to spread the financial and technological risk. This trend, he thinks, will be especially evident in the international chemical field. Already, several European firms are moving into the U.S. market, either jointly with American producers, or on their own. Dow-Badische (Badische-Anilin) and Mobay (Monsanto-Bayer Farbenfabriken) are now building plants in the U.S., and Imperial Chemical Industries (England) and Celanese have announced a joint venture in Shelby, North Carolina, to make polyester fibers. Montecatini (Italy) has an eleven million pound polypropylene plant under construction in Neal, West Virginia, and Saint Gobain (France) recently unveiled plans to finance a new glass plant in Greenland, Tennessee.

Finally, president Grace predicts that expansion in new chemical plants, in the period 1960-1962, will move to a new high, reflecting cutbacks in spending during the past eighteen months. Certain chemicals, formerly on the overcapacity list, have now become short due to cutbacks in capital spending while new demand increased. This factor, plus the vastly improved 1959 earnings picture will, in his opinion, lead to another boom construction period in the near future.

Too much high-density polyethylene

"Markets for high-density polyethylene are glutted," says the research department of Smith, Barney & Co. large brokerage firm. "Industry consensus," continues the report, "seems to be that production this year of the high density grade is around 50% of a capacity of 265 million pounds, and that even at 20% of capacity there would be plenty of the material available."

Pipe fabrication know-how going to USSR

An American-made plant for production of plastic pipe will be shipped to the Soviet Union by Omni Products. The contract, approved by the Department of Commerce, covers a complete plant, including extruders, grinders, and dies. Capacity of the plant is said to be about 10,000 tons per year of piping, payment will be made in cash in American dollars. According to Omni, the sale in no way conflicts with the position taken by MCA earlier this year against export to Russia of chemical know-how and equipment, since the plant in question is for end use production only, and since the product is said to be slated for irrigation purposes rather than strategic or military use.

More corporate $$ for higher education

A 23.5% increase in corporate aid to education over the two years from 1956 to 1958 is revealed by results of a recent survey of the country's 1,500 largest corporations; the survey was carried out by the Council for Financial Aid to Education. Highest average gift per company was in the electrical machinery field, with 11 companies averaging $336,366 in education grants for 1958. In second place was the chemical industry, with 25 companies averaging $247,371 each, followed by the tobacco industry, with 3 companies averaging $247,353 each.

"These increases were made during an 'off profit' year," said F. H. Sparks, president of the Council, adding, "This is encouraging evidence that the most alert business management in the world regards the financial support of higher education as of the first importance."

Unrestricted gifts far outweighed any other type of giving to colleges in 1958. This fact, according to CFAE, "indicated a statesmanship and thoughtfulness in corporate aid to colleges, and was one of the most encouraging finding of the survey." Unrestricted gifts amounted to $16,619,255, or 34.1% of the total of $48,771,277 given by 352 companies answering this part of the questionnaire. Of the designated grants, buildings and equipment commanded the greatest return, accounting for nearly 17% of the total given.

Other increases noted in the survey were found in the rate of giving, and the amounts contributed by individual companies. Twenty-eight companies during 1958 contributed to education at the rate of one percent or more of net income before taxes. This number is twice that for the "one percent club" in the 1956 survey—a sizable jump, since the number of participants in the present survey increased by only one-quarter. Almost twice as many companies are giving $100,000 or more to education—91 companies in 1958, as against 55 in 1956.

Eight companies contributed despite operating losses in 1958. The establishment of corporate foundations helped 157 of the companies to maintain continuity of giving in spite of earning fluctuations, and one company, through its foundation, gave almost four times as much as it earned in 1958.

Education received 28.4% of the corporate gift dollar contributed for all causes during 1958, according to 339 companies reporting their total programs in the present survey. Thirty-three of these gave more than one-half of their total philanthropic budget to education.

"This kind of voluntary support from corporations can perhaps make it unnecessary for the Federal Government to do much more in this field than it is now doing," says Council president Sparks, "If every corporation did proportionately as well as these companies, we would be well along toward meeting the emergency in the financing of higher education in America."

From here and there

Design, engineering, equipment procurement for a 30 metric ton per day edible oil plant for Iran has been assumed by Chemetron's Girdler Process Division . . . Monsanto Argentina is installing facilities to produce polyvinyl chloride compounds at its plant in Zarate, near Buenos Aires . . . Koninklijke Zwavelzuurfabrieken v/h Ketjen, N.V., Amsterdam, The Netherlands, will build a plant for production of synthetic phenol, by-product will be anhydrous sodium sulfite . . . General Electric announces development of a new process for conversion of salt or brackish water. Claimed is decrease in overall resistance to heat flow through use of thin films of water for both evaporation and condensation . . . Major expansions at Union Carbide's Seadrift and Texas City, Texas, polyethylene plants will add 170 million pounds per year to the company's output of the high-pressure variety.

EJC to study advisability of national engineering register

On behalf of the National Science Foundation, Engineers Joint Council will undertake a complete study of the advisability of establishing a representative register of engineers as part of NSF's National Register of Scientific and Technical Personnel. Objective—"A full report to NSF on recommendations from the engineering profession, industry, and educators on the desirability, feasibility, and methodology of a complete national register."

SCOPE

Big producers betting on maleic, fumaric

Drastic price slash, effective in January, 1960, have been announced by both Monsanto and Allied Chemical for maleic anhydride and fumaric acid, both basic ingredients in manufacture of polyester resins and alkyds. The price cuts, together with large construction programs mapped out for both intermediates, seem to indicate almost unlimited faith in growing market demand. (Total U.S. production of maleic is estimated by Monsanto at 65 million annual pounds, more than half of which goes into polyester resins, alkyd-based paints, other hard resin surface coatings).

Effective on 1960 contracts, Monsanto's new tank car price on maleic will be 22¾ cents/lb., freight equalized. This represents a reduction of approximately five cents under the current list price of 27¾ cents. Construction will begin shortly, says the company, on 20 million pounds of new maleic capacity at its John F. Queeny Plant in St. Louis, which is now turning out 40 million pounds per year. Production in the added facilities is slated for the third quarter of 1960.

Allied Chemical's National Aniline Division will match Monsanto's cut on maleic—announced prices, also effective in January, 1960, are 23¾ cents for rods and tablets, 22¾ cents for the molten product, carload quantities. In less than carload quantities, Allied's new price will be 25 cents.

In fumaric, Allied will erect new production facilities at Moundsville, West Virginia, scheduled to go on stream by June, 1960. The new facility, says Allied, will double its present fumaric capacity, and will add to previously announced construction already under way.

The announcement of the new construction program is linked by Allied to price cuts similar to those simultaneously made public for maleic. Starting in January, carload quantities will cost 22¾ cents, a cut of 4¾ cents. Less than carload quantities will be priced at 24¾ cents. Here, again, Monsanto has exactly matched the price reductions announced by Allied. According to Monsanto, the reductions should further stimulate the mounting interest in fumaric acid indicated by its increased use—a growth rate of about 15% annually during the last two years.

New natural gas strikes in Italy

In Northern Italy, new deposits are reported in the Po Valley at Spilambergo, near Modena, and at Brugherio and Cernusco sul Naviglio near Milan. In Southern Italy a new discovery has been made at Ferrandini, and in Sicily near Castelvetrano.

Polycarbonate polymer patents pooled

A cross-license patent agreement on polycarbonate polymers has been concluded between General Electric and Farbenfabriken Bayer (West Germany). The pooling of know-how on the new class of polymers, developed independently by the two companies, will be exploited by General Electric at a new plant now under construction near Mount Vernon, Indiana—production is slated for mid-1960. Coatings, fluids, elastomers, film, molding compounds, extrusion materials are expected to provide a growing market for the polymers which are claimed to exhibit high impact strength, good dimensional stability, superior heat resistance, excellent electrical properties.

Operation HAYSTAQ—automatic searching of chemical literature

An experimental computer program, HAYSTAQ, has been organized by the National Bureau of Standards and the Patent Office. Objectives: to determine the characteristics of large-scale information systems; to test search strategies; to test suitability of computer equipment for conducting the search; to provide a working basis for the construction of improved search systems.

Solid fuel contract to National Research

A Defense Department research and development contract on high-energy solid propellant missile fuels has been awarded to National Research Corp. "The program involves certain vacuum processes, materials, and techniques which the company has been perfecting under its own sponsorship for more than a year," says National Research.

New horizons in heat transfer

GLENN B. WARREN, *President*
American Society of Mechanical Engineers

In a post-World War II appraisal of the technological needs and deficiencies in my own company, we came up with an understanding that our two greatest deficiencies existed in the heat transfer and metallurgical areas. We thought then that these two areas contained more limiting factors on our further technological development than any other, and that furthermore we were more ill-equipped here to handle the advancing technological needs. Accordingly, steps were taken to begin to overcome these deficiencies.

With respect to heat transfer at that time, we thought we needed additional information in connection with (1) electrical machine performance, that is, increased and more uniform heat dissipation; (2) increased knowledge in connection with power plant machinery, that is, with respect to boilers, superheaters, resuperheaters, condensers, feedwater heaters, etc.; (3) cooling of internal combustion machinery, that is, automobiles, airplane engines, etc.; (4) heat transfer in connection with commercial and domestic refrigerators, stoves, air conditioners, etc.; and (5) in connection with chemical processes in the chemical and petroleum industries.

In general, however, all of these needs were characterized by relatively *low rates of heat transfer*. Only in the evaporative parts of *large marine power boilers* was there apparent need for fairly high rates of heat transfer...

Within a few years however, the explosive needs of new technology demanded consideration of heat transfer requirements that were almost a whole order of magnitude or more in advance of what we had all been doing up to this time.

New and more scientific ventilation concepts for electrical machinery were worked out which in many cases permitted a 50 to 100 percent increase in capability for a given frame size. New insulations were developed which permitted higher temperatures and, hence, increased heat dissipation for any given ventilating system.

Then, we began to apply an old concept of cooling electrical machinery by forcing either gas, or liquid, through hollow electrical conductors, direct cooling we called it, which eliminated the dam to heat transfer that the electrical insulation itself had always been. In large turbine-generators this has permitted an additional 2 to almost 4 to 1 increase in the capability from given basic frame sizes . . .

Then in power machinery, single power plant boilers have increased from a maximum of some hundred thousand kilowatts twenty years ago, to 400,000 KW, and now even 500,000 KW today. Higher steam pressures and high steam temperatures have multiplied the problems. The heat of evaporation has had to be put in at nearly 700°F, the superheat has had to be transmitted through tubes to steam from 1000°F to 1150°F in plants which are in operation today. Steam pressures have gone from 1200 lb./sq. in. of twenty years ago, to 4500 and 5000 lb./sq. in. in some cases today. Twenty-four hundred lb./sq. in. is standard and 3500 lb./sq. in. will probably be more or less standard in another two years.

Complicating this heat transfer problem, the feedwater in these new boilers has had to become chemically pure to an unprecedented extent if it is not to form deposits to which the newer, higher temperature, higher heat transfer rate, boiler tubes are much more sensitive. Purity of feedwater is now measured in parts per billion, not parts per million as formerly, and it must be treated with chemicals which leave no solid residue.

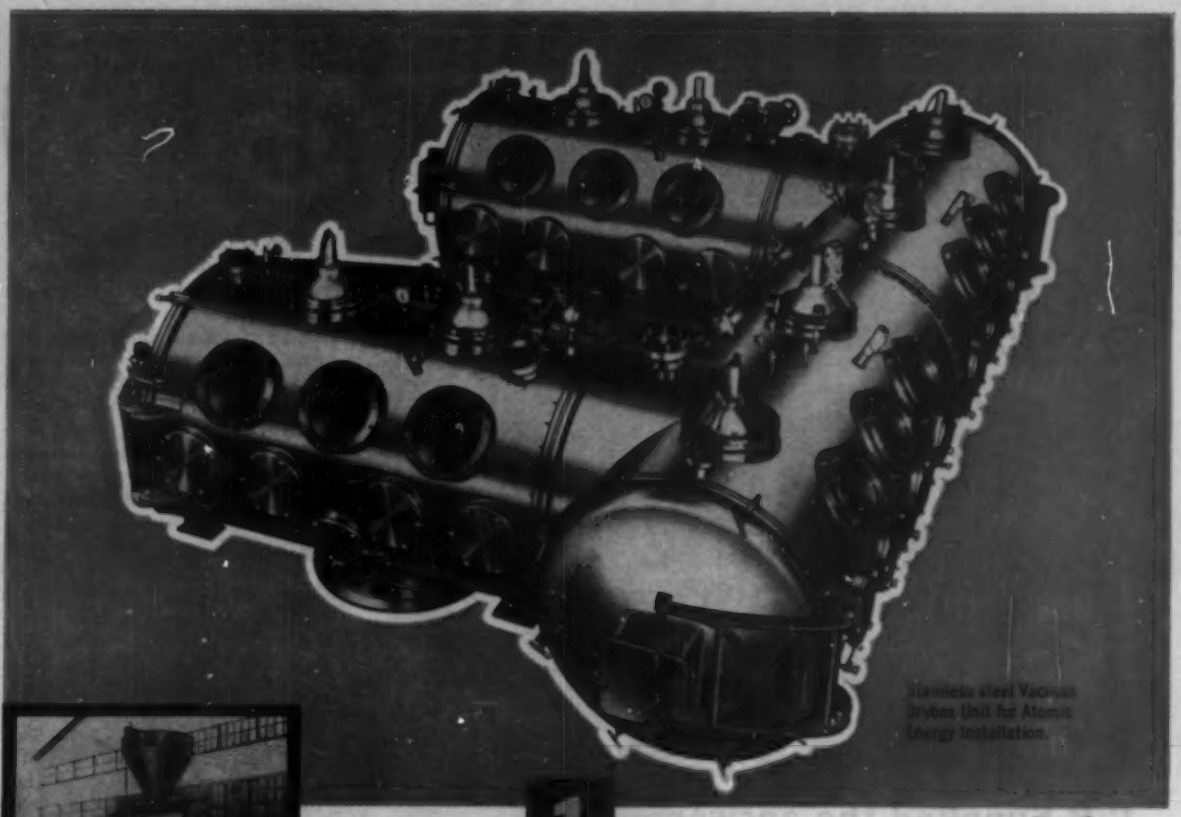
The problems we have been talking about, however, become simple in many respects compared to those involved in connection with heat transfer in nuclear power reactors. Here, although I have few exact figures, I am inclined to believe from what I do know that in some of these reactors the heat transfer rates must be three to five times what they have been in the highest rated fossil fuel boilers to date. In this connection, not only are ordinary ferritic and austenitic materials involved, but new and exotic materials must frequently be used because of a whole new scientific concept, that is, "neutron economy", a phrase and concept totally unknown a generation ago.

If we look at the gas turbine, we find a whole host of new kinds of heat transfer problems: turbine wheel cooling, turbine bucket and nozzle cooling, combustion chamber liner cooling, regeneration of exhaust heat, i.e., the putting of this heat back into the inlet compressed air on its way to the combustion chambers to save fuel, and compressor intercooling. In the gas turbine, all of these processes must transfer fantastic quantities of heat, usually from gas to gas, with but small temperature and pressure differences and with counter flow, or else the purpose of heat transfer itself is defeated.

On the airplane gas turbine, many of these problems become acute. In some cases we are cooling turbine wheels, liners, nozzles, buckets, etc. with 700°F to 800°F air, and then we drive these new planes so fast that cooling problems develop in the cockpit and, further, we must cool the lubricating oil by the fuel going to the gas turbine. We must also develop air conditioning systems light in weight and tremendous in capability to meet these problems.

With respect to new rocket technology, we must handle oxidizers at many hundreds of degrees below zero, while combustion temperatures must be measured in the thousands. Light weight and high strength are very important. In some cases, gears must be run at fantastic temperatures, speeds, outputs, and with fantastic lubricants.

continued on page 28



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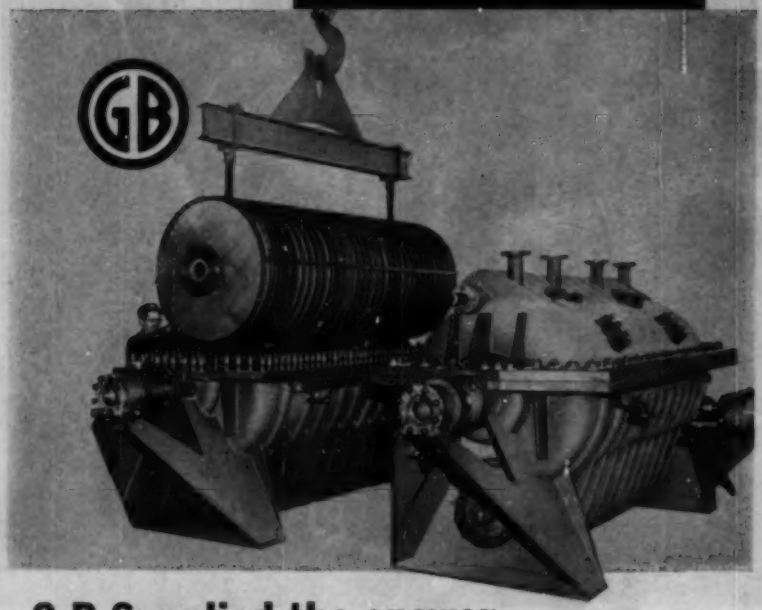

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Heat transfer

from page 26

The nose cone and its re-entrant problems, man in space problems, dissipation of heat from satellites, etc., all pose new problems of heat transfer never dreamed of a generation ago.

The growth of air conditioning, the corollary growth of the heat pump, and the need for heat storage which must be used with this if it is to be an economical electrical load for the public utilities in domestic and commercial heating, posed new problems. The air conditioning of motor cars with the low-cost, low-power absorbing equipment poses new problems. The other day I heard talk of possibly air conditioning whole towns, although I must confess at the moment I do not know the details.

There are two new areas of technology that may make new and different demands on the science of heat transfer. I am referring in the first place to the growing awareness of a need for a low-cost means of producing fresh water from salt. Many processes are under study, but I suspect that the multiple-effect evaporative process will have quite wide application. Here we need to be able to do the job for lower cost than by any of the present available schemes.

The second has to do with the probable use of H-bombs in underground explosions to develop power and to drive oil and gas out of lean oil-bearing rocks and sand, etc. These will mean new and altogether different concepts of heat transfer than probably any that we have ever had before . . .

What I have tried to emphasize is that heat transfer is a growing and dynamic field of technology which has tremendous potentialities for growth and application to meet the expanding needs of this Age of Science and Engineering. A fine job is being done, it seems to me, in laying the basic foundations to meet these needs, and, I would think, this could hasten the reduction to practice in many areas by emphasis, not in place of the fundamentals but to supplement these, on the application and design areas of this growing and changing field of technology.

Excerpted from an address at the 1959 ASME—A.I.Ch.E. Heat Transfer Conference and Exhibit, Univ. of Conn., Storrs, Conn., August 9-12, 1959.

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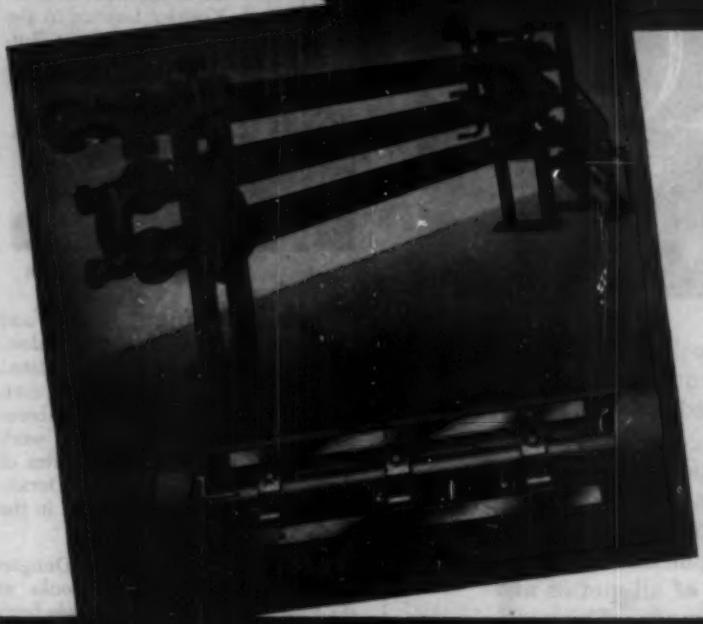
BELOW: *A scraped surface unit for production of Para-Xylene by fractional crystallization. Insert shows detail of Vogt Spring Type Scraper.*



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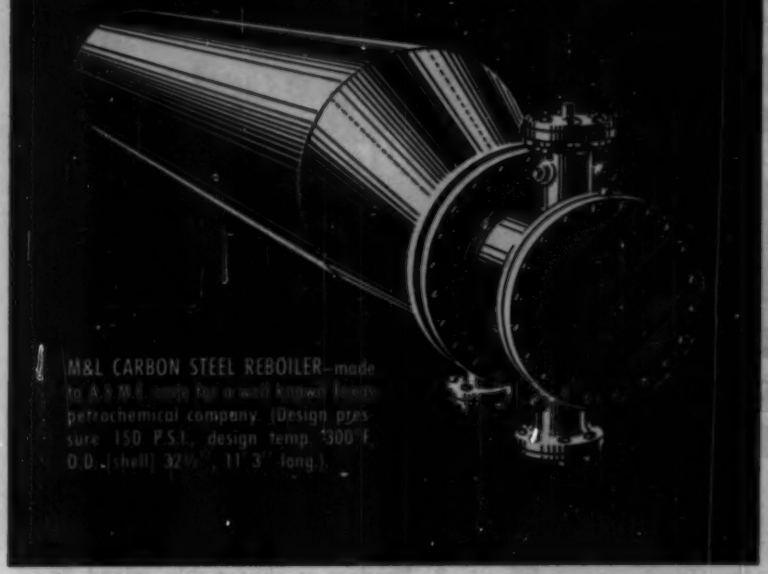

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about our authors

from page 12

tion. All three men are at Oak Ridge National Laboratory, Tennessee.

T. L. Koehler, Jr. (*Evolutionary Operation—a program for Optimizing Plant Operation*) is head of the statistical analysis section at American Cyanamid Bound Brook, N.J., where the experiment in Evolutionary Operation took place. His work at Cyanamid has been mostly application of modern concepts of experimental statistics to research, development and, in particular, process improvement. In addition to holding this post, Koehler teaches in the Graduate School of Statistics at Rutgers.

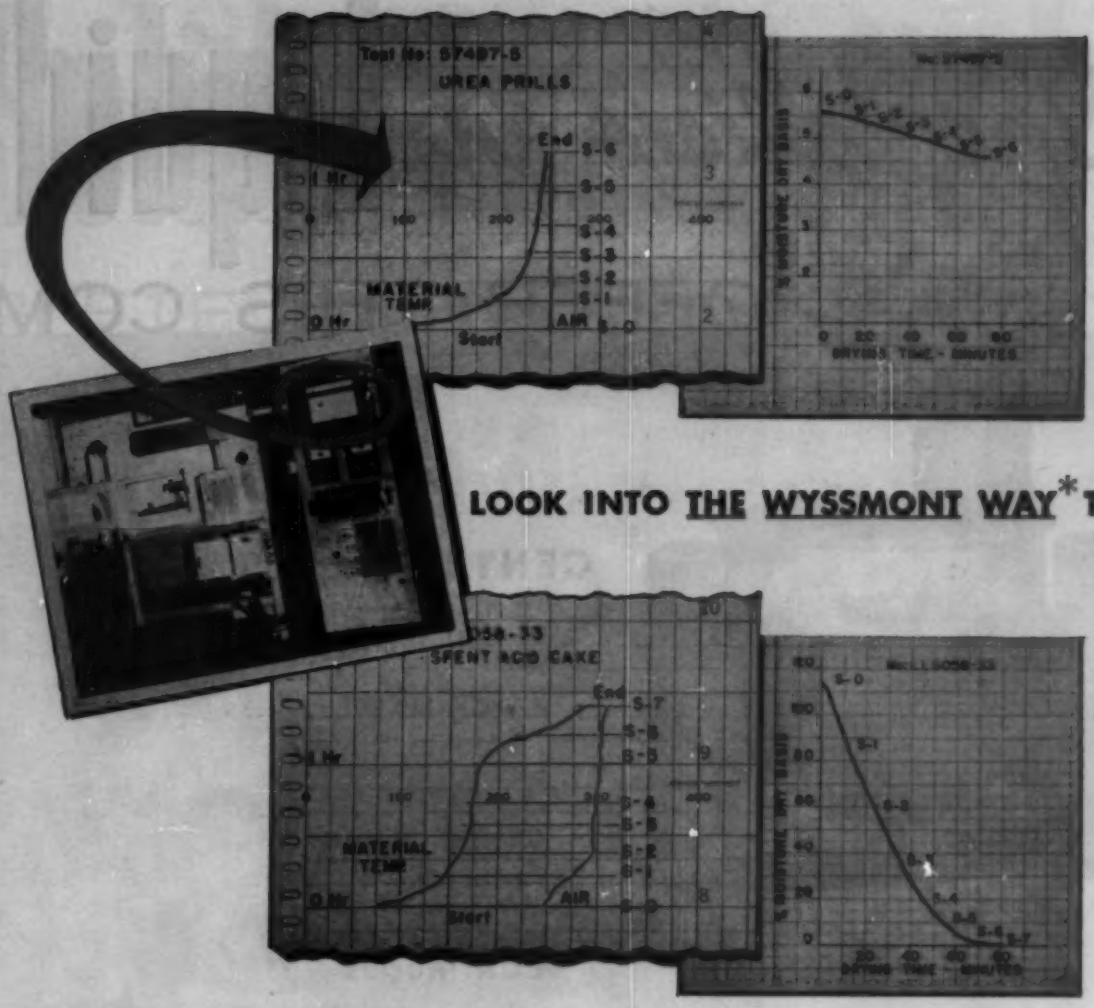
Gaertner Doraiswamy Bijawat

L. K. Doraiswamy, H. C. Bijawat, and M. V. Kunte (*Fluidized Bed Chlorination of Ilmenite*) were associated with the chemical engineering division of the National Chemical Laboratory, Poona, India, when the work was done. All three are graduates of leading Indian Universities. Doraiswamy and Bijawat also studied in the United States.

G. B. Zimmerman and T. A. Dungan (*An Engineer Contractor Looks at the Pilot Plant*) wrote this article from experience at Bechtel Corp., in San Francisco, California.

Construction is underway on a contact sulfuric acid plant at Nichols, Florida, for the Virginia-Carolina Chemical Corp. Elemental sulfur will be used as a raw material, Monsanto vanadium sulfuric acid catalyst. The acid will be used for additional production of phosphate rocks, phosphoric acid fertilizers. Rated capacity of the unit is 500 tons daily. Engineering is by Leonard Construction.

Another sulfuric acid plant just went on stream at Pocatello, Idaho. The 400 ton day unit of J. R. Simplot company, uses recovered sulfur from local refineries, and Monsanto vanadium sulfuric acid catalyst. The sulfuric acid is used for increased production of wet process phosphoric acid. This in turn goes into the manufacture of phosphate fertilizers.



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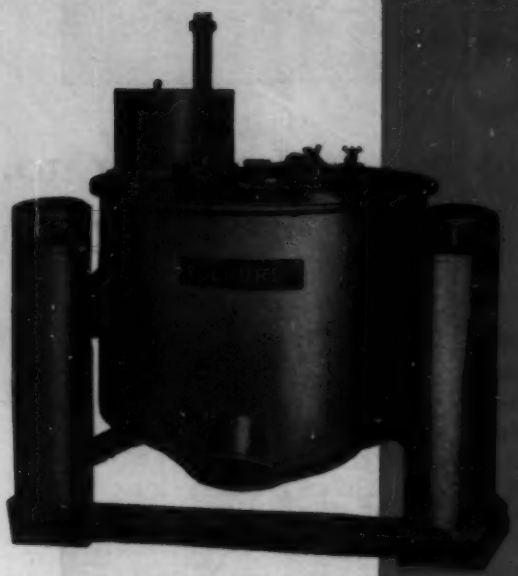

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Chemistry—Spearhead of Cancer Research

Chemotherapy, a relatively new word in the medical vocabulary, is assuming a more and more vital role in the fight against cancer. More than $20 million is being spent annually in the U.S. in testing chemical compounds for their action on cancer. Much of the program in this country is under the guidance of the Cancer Chemotherapy National Service Center, part of the National Public Health Service. In the screening program of the Service Center, about 10,500 synthetic chemical compounds are said to have been tested in animals according to a standard pattern, and 126 of them found interesting enough for further study.

Of the private and public organizations participating in the overall chemotherapy effort, one of the first in the field, and perhaps today the most important, is the Sloan-Kettering Institute for Cancer Research in New York. Sloan-Kettering alone is now reported to have tested more than 59,000 compounds. Of these only about a dozen have been useful in the clinic, and several hundred more are worth further study. These compounds fall into four chemical groups:

1) Polyfunctional alkylating agents, related in action to the nitrogen mustards. Most widely used compounds of this type are nitrogen mustard, chlorambucil, TEM, thio-TEPA, and busulfan (Myleran).

2) Antimetabolites such as antifolics (Amethopterin), the purine analogues (6-mercaptopurine), and glutamine antagonists (azaserine).

3) Sex hormones, such as estrogens, androgens, and the adrenal steroids (cortisone).

4) Miscellaneous, including actinomycins, colchicine, urethane.

"It is extremely unlikely that any one drug will prove to be a panacea for all types of cancer" says Dr. C. Chester Stock, associate director of Sloan-Kettering. Rather, he thinks, as in the case of the so-called "wonder drugs," a whole series of chemical compounds will be necessary. Behind this reasoning is the fact that normal body cells themselves present a wide spectrum of differences. Therefore, it is logical to suppose that diseased or cancerous cells will be of many different types. In fact, points out Stock, the biggest problem of all is the very small difference between normal and cancerous cells. There is not presently known to exist any single characteristic of all cancer cells which could serve to distinguish them from all normal cells. Prime objective here is to find some "exploitable" difference as a basis for tests and for development of specific chemical agents for clinical use.

"A vital part of the work," says Stock, "is the search, not only for new compounds, but for new methods and procedures for testing and evalution." This is being carried out with the cooperation of a large number of clinical testing centers at public, private, and university hospitals. During the last few years, according to Stock, Congressional grants and other sources have provided ample funds to carry on the work. The real shortage now is adequately trained personnel. This, however, is expected to be brought quickly under control by present training programs.

Liaison with groups in other countries working on the same problem is maintained both by the National Service Center and by Sloan-Kettering and other private research organizations.

What causes cancer?
Is it increasing? Is it contagious?

Interesting speculations. In the first place, with the large number of infectious diseases which have been virtually eliminated as serious threats during the last century, and the resulting increased average span of human life, the percentage of people who die of cancer has increased automatically—one might almost say, by default. In the second place, there is the possibility, points out Stock, that phenomena associated with the progress of certain of these infectious diseases develop within the body substances which either destroy or inhibit the growth of cancer cells.

While experts are reluctant to say that cancer as a whole is on the increase, they are statistically sure that lung cancer is definitely increasing at a terrifying rate. Why? Speculations include the effects of increased radiation levels, the evermounting use of antibiotics, cigarette smoking, atmospheric pollution, or more probably a combination of several factors.

But, the battle goes on—and in the forefront are the searchers for new chemicals, one or more of which will one day unlock the door.

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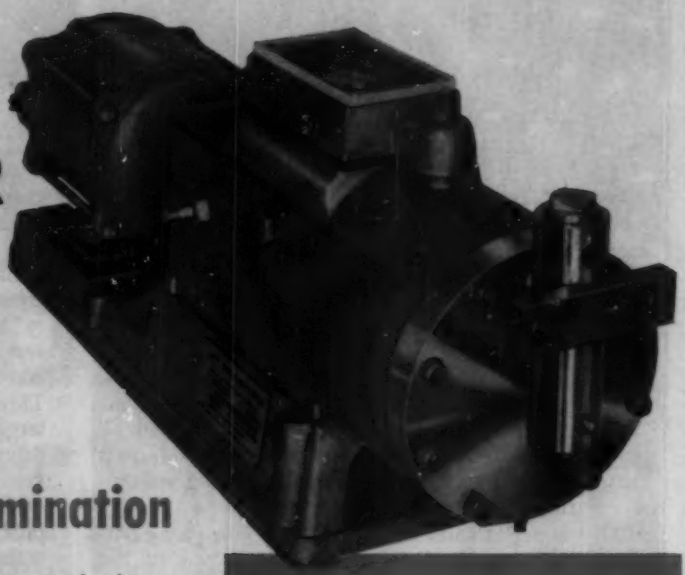

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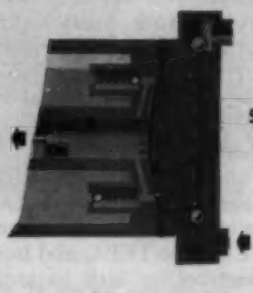
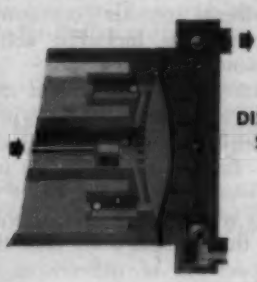




WRITE FOR BULLETIN 440 containing typical applications, flow charts, description and specifications of models of various capacities and constructions and special leakage chart. Lapp Insulator Co., Inc., Process Equipment Division, 3713 Poplar St., Le Roy, New York.

Lapp

For more information, turn to Data Service card, circle No. 14

opinion and comment

Corporate giving —a first step

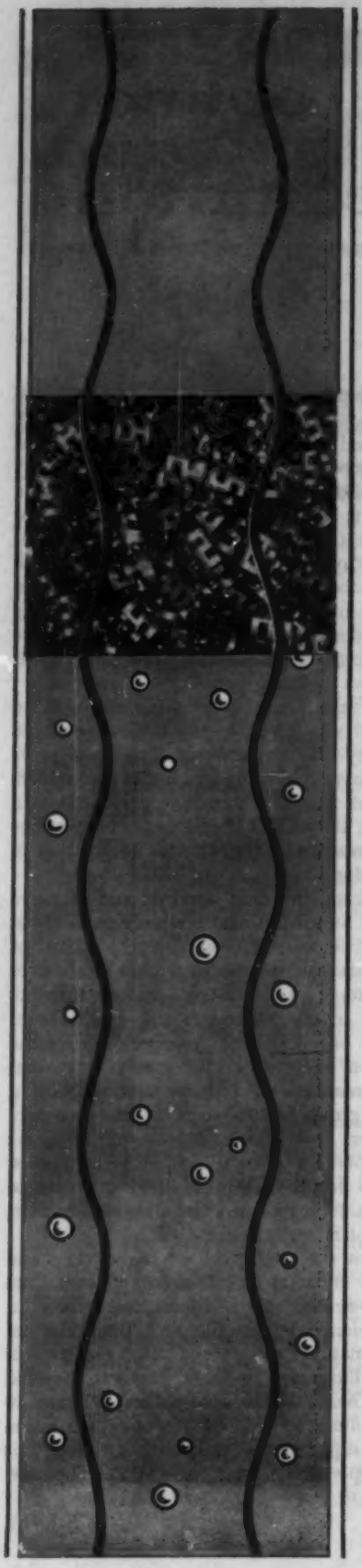
The days when a university consisted of Mark Hopkins on one end of a log with a pupil on the other have long since passed. Education today is more expensive than ever, and the student who sits on one end of a log with his teacher on the other end is probably chipping off samples for a carbon-14 dating experiment. While the primary function of a teacher is still to reach a student's mind, education now requires expensive research tools and facilities to aid the mind, once it is reached, to expand and to explore new paths. All this is hardly news, nor is it news that colleges need money or that American corporations in a uniquely American gesture are contributing huge sums to educational processes. How much this amounts to, though, may come as news to many people.

According to the recent report of the Council for Financial Aid to Education, in 1958 almost $48,771,000 was given to the nation's colleges and universities by three hundred fifty-two corporations. The good news about the survey is that, despite less favorable business conditions in 1958, the net trend of giving was up about 24% in a two-year period. It is a trend which is most encouraging, for it shows that the nation's corporations affirm one of the most important reasons for America's unique position in the world—wide and available education.

The council extrapolated the data from the three hundred and fifty-two companies to conclude that all United States business concerns gave about $136,500,000 to education. We are particularly interested in the record of the chemical industry: twenty-five companies reporting gave well over $6,000,000 to education for a percentage of net income before taxes of 0.47. This is a reasonably high total in comparison to the donations of other groups. As a matter of fact, the only industrial groups ahead of the chemical firms were the transportation equipment (twenty-six companies with 0.93 percent), textiles (0.58 percent), and printing and publishing (0.85 percent). The lowest industrial group was tobacco, which gave only 0.04 percent to education. The leaders in the chemical classification, six companies, gave to education 0.81 percent of net income before taxes. One other fact ought to be reported for the chemical field—contrary to the general tendency, contributions in 1958 reflected the state of business, since they were down some 2.6 percent from those for 1956.

Although business gifts are far below the total given by foundations and alumni groups, the trend is extremely encouraging. It points to a gradual realization that first things should be first. There is a great need for educated men in all fields, not only in science and engineering. But today, of course, these last are preempting the nation's attention; indeed the government's generosity in giving away billions for scientific research has led some experts to express doubt that there will be enough trained men to work on all the projects that could be financed. To get these men, education must be extended. Education needs support, and business in giving it is at the same time recognizing its dependence upon education. The new trend is, in a word, good business.

F.J.V.A



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1. Lowest pressure drop
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Metal Pall Rings are available in ⅝", 1", 1½" and 2" sizes in carbon steel, stainless steel, nickel, monel, inconel, titanium, copper and aluminum.

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*Pfannmuller, W., TRANS. INST'N. CHEM. ENGRS., Vol. 32, 1954, Supplement, pp.151 ff. Eckert, J. S., et al., CHEMICAL ENGINEERING PROCESS, Jan. 1958, pp. 70 ff.

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OCTOBER CEP 1959
FEATURE

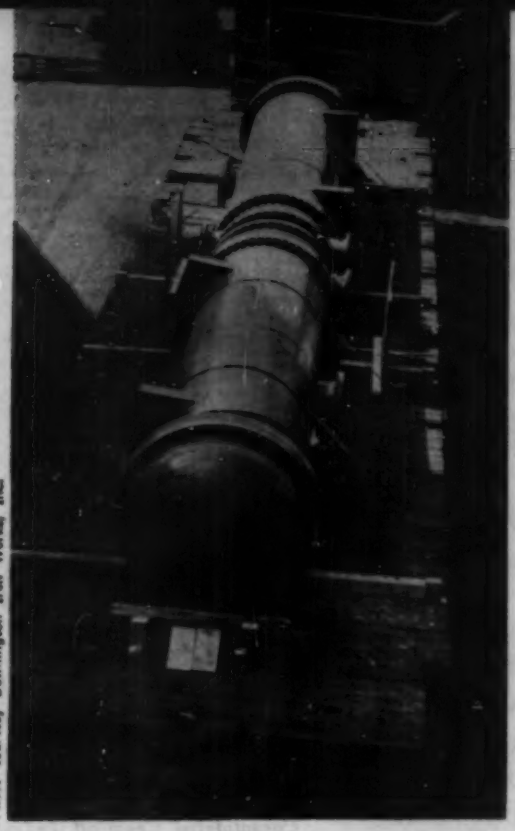

Photo courtesy Downington Iron Works, Inc.

. . . new concepts and methods in the chemical engineering practice of

Heat Transfer

Energy and its use is one of the keystones of engineering. Its efficient utilization can mean the difference between failure and feasibility. Heat transfer is one method of energy interchange and conservation, and the application of new heat transfer data to industrial practice is the devoted interest of a large segment of the engineering population. In the forefront of this interest is the chemical engineer, for complicating his normal engineering search for more efficient transfer methods is the fact that chemical reactions are often sensitive to narrow ranges of temperature. This means that for a chemical process, and for the chemical engineer designing or operating it, the commercial product is not merely a matter of over-all efficiency of heat transfer, but a matter of heat transfer within narrow ranges of temperature and within certain rates or periods of time. This is why heat transfer will always be of extreme interest to chemical engineers, and why they are so avid for the penetrating study, and for the interpretation, of phenomena in mathematical and scientific terms. Just recently, the chemical and the mechanical engineers together ranged over the whole subject of heat transfer at the Storrs, Connecticut, conference. The editors of *Chemical Engineering Progress*, aided by the Heat Transfer Division of A.I.Ch.E., especially Mario Cichelli, Papers Committee Chairman, have selected from this conference six of the newest and most practical articles in the field.

One of the triumphs of these conferences is the constant use of experimental data to design and plan industrial installations—such is the first article on the application of a theoretical analogy to a complete plant. This then has become the historic role of engineering meetings—a common ground for the interchange of experiences, where the men who must make the plants work meet and talk with those who are concerned with the basic mechanisms of engineering. As Max Jakob said in his second edition of *Elements of Heat Transfer*, "the subjects of converting and conveying heat energy are of similar importance." This is true, but in the converting and conveying of the heat energy there is a vast army of engineers all devoted to the exhausting pursuit of a better understanding of this mechanism.

28 pages of Heat Transfer! CEP's annual feature brings you up-to-date in this vital area

Heat and mass transfer analogy

...an appraisal using plant scale data

The Colburn & Hougen analysis established for designing apparatus to condense vapor from vapor-noncondensable gas mixtures — equipment having small inlet concentrations of condensables — is also applicable to partial condensers and dephlegmators.

J. F. Revilock
National Carbon Company Div., Union Carbide Corp., Cleveland, Ohio
H. Z. Hurlburt, D. R. Brake, and E. G. Lang
Stauffer Chemical Company Consolidated Chemical Industries Div., Houston, Texas
D. Q. Kern
D. Q. Kern Associates, Cleveland, Ohio

The Colburn and Hougen (*6*) method establishes a basis for the computation of simultaneous heat and mass transfer and is our most powerful tool for computing the rate of condensation of a vapor from a noncondensable gas. Since the publication of the analogy twenty-five years ago (*4*), numerous papers (*1, 2, 3, 5, 8, 15, 16*) have appeared endeavoring to refine or shorten the time required for the solution of condenser-cooler problems. The computer reduces the importance of time as a consideration in any of the methods. Based on the modification of Kern, Franks and O'Brien (*7, 13*) have published a program for an analog computer which requires but a few seconds for a complete solution. Digital computer programs are presently also in use (*11, 12*). No article, however, has ever verified the precision of the analogy in a large-scale application.

It is the object of this article to supply the results of such a study and to contribute to the appraisal of the analogy and its applicability to industrial design.

In a single tube it is simple to determine the average vapor-gas velocity at any point along the length of the tube, since all of the material is carried by the single tube. In a multiple-tube, single-pass heat exchanger, the distribution of the mixture among the tubes may not be equal and will vary with the orientation of the nozzles relative to the channels. When a group of exchangers is operated in parallel off the same

uniform main, there is the added factor of unequal gross flow in each exchanger which varies with the method of manifolding.

It is not surprising that there is a dearth of data verifying the analogy on a large scale. While the use of such equipment as compressor inter- and after-coolers is widespread, the data obtained from them usually cannot be computed to provide conclusions significant to the precision of the analogy. In most instances the vapor-gas mixture is circulated on the shell side rather than the tube side of a multipass condenser-cooler and it is not possible, by methods currently available, to set up the precise temperature differences between the vapor-gas mixture and each water pass. Also, much of the equipment which has been designed on the basis of the analogy is employed for the purpose of removing as much condensable vapor as possible. In such apparatus, there is frequently a very close approach between the inlet temperature of the cooling medium and the outlet temperature of the vapor-noncondensable gas. In such a case, an observation error of a half degree or a degree in the counterflow outlet terminal temperature difference would represent a substantial deviation from the values predicted by the analogy.

In addition, there is always some discrepancy in closing the heat balances in plant scale apparatus when dealing with hot diffusing gases on one side and cooling water on the

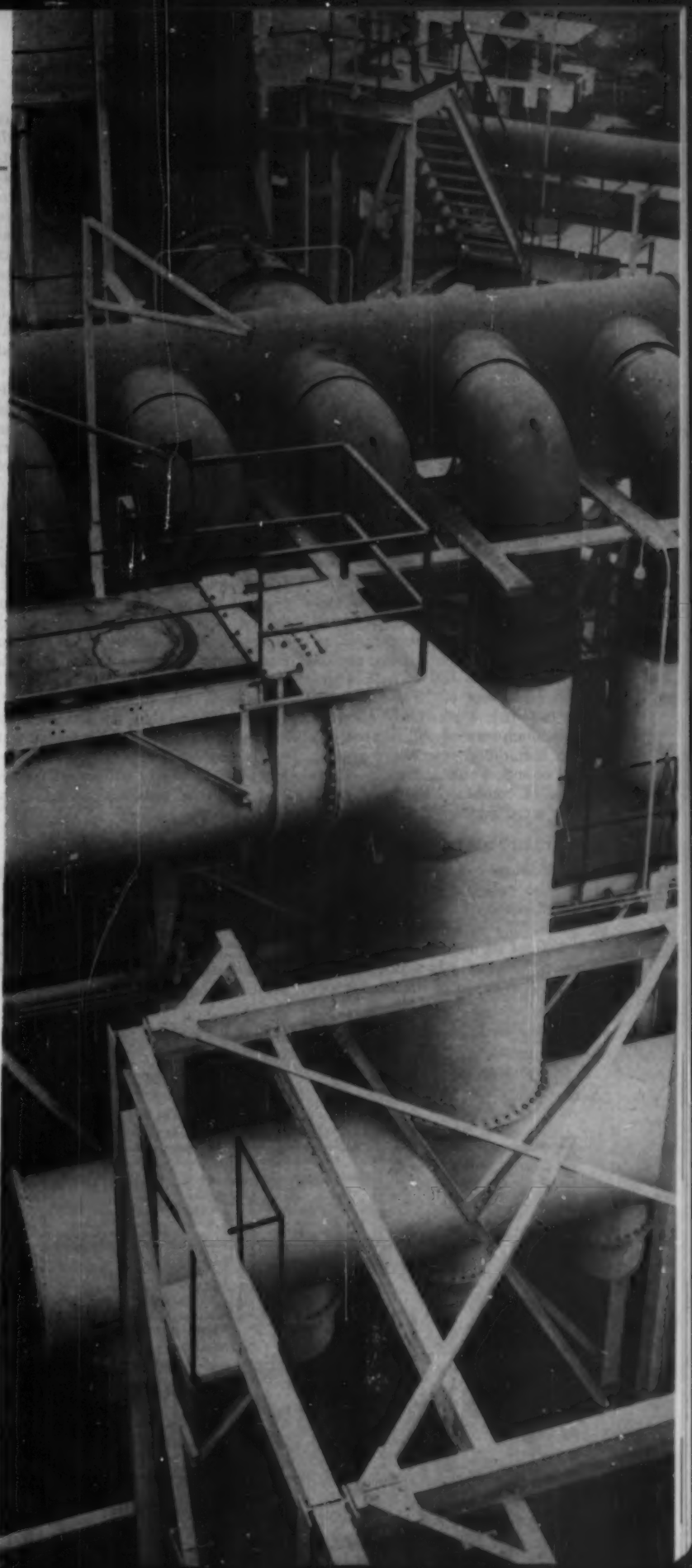

Figure 1. "Karbate" heat exchanger installed in a plant of Consolidated Chemical Industries Div., Stauffer Chemical Co. is shown at bottom. Cooler positions run left to right.

other. This discrepancy is usually much greater than anticipated due to difficulties in the measurements of temperature, pressure, and flow which must often be made at some distance from the apparatus and under the influence of servomechanism effects. Fortunately, impervious graphite has long been used for the condensation of vapors from various corrosive gases, and the vapor-gas mixture is circulated through the tubes to avoid corrosion to the steel shell.

A battery of six 37-in. I.D. vertical counterflow exchangers, each having 439 x 1¼ in. O.D. x ⅞ in. I.D. Karbate tubes by 14 ft. long, are operated in parallel by Stauffer Chemical Co. to cool and dehumidify gases resulting from the combustion of acid sludge and spent alkylate H_2SO_4. The hot gases from the furnaces are immediately quenched by adiabatic humidification with dilute H_2SO_4 prior to entering the exchangers. During the tests described here the exchangers were operated with a relatively large, cold terminal temperature difference.

continued

Analogy

continued

There has been prejudice in chemical engineering practice toward the use of intermediate adiabatic quenching, since the total heat content of the resulting vapor-gas mixture remains unchanged while the temperature at which the heat becomes available is greatly reduced. Through the use of the Colburn and Hougen analysis, it can be shown that, for a broad area of application, the heat transfer coefficient for a vapor-gas mixture may increase through adiabatic humidification at a much greater rate than the over-all temperature difference decreases. Under low available pressure drops of 3 to 5 in. H_2O, a furnace gas at 1800°F can be cooled by sensible heat transfer to a temperature of 100°F with a coefficient of about 2.0 Btu./(hr.) (sq. ft.) (°F). The same gas can be adiabatically humidified to a dew point of 175 to 165°F and the mixture cooled and condensed to 100°F with a vapor-gas coefficient of 75 to 85 Btu./(hr.) (sq. ft.) (°F). Only about a third as much surface will be required for the humidified gas. There appear to be countless instances in which this use of combined heat and mass transfer merit additional investigation.

Apparatus and Data

In addition to the data already given, the tubes of the exchangers were laid out on 1-35/64 in. triangular pitch. The bundle contained sixteen 25%-cut segmental baffles, equally spaced. Figure 1 is a photograph. An outline drawing of the exchangers is shown in Figure 2. Five exchangers were originally installed and the sixth exchanger was added later, accounting for the asymmetry of the ductwork. While the furnace was operated at a substantial excess of full-scale capacity during the test period, variations in the performance of the six exchangers were carried out to cause a minimum interference to production. Flow on the tube side or shell side of any exchanger could be completely cut off. Valves were not used for throttling. To this extent the combination of shell and tube side conditions were carried out as shown in Table 1, the numbers in the table indicating the number of exchangers through which the *total* quantities of gas and water flowed.

Runs 1, 3, and 4 represent variations in the gas side velocities as well as the water flow velocities. Runs 2 and 5 represent changes in the approach temperature through the decreased use of water. All tests, conducted during a 24-hour period, represent steady-state conditions on freshly cleaned equipment, and the data are presented in Tables 2 through 5. The identities of Runs 1 and 6 indicate that no deposition of dirt or sulfur occurred during the test. All orifices and temperature measuring devices were calibrated before and after the tests and found to be constant.

The furnace gas composition on a dry basis was:

SO_2=8.9%, CO_2=13.9%, O_2=2.2%, N_2=75.0%. The hot gas entered a scrubber where it was presumably adiabatically saturated with 15.6% H_2SO_4. From the scrubber it passed to the coolers. The temperature of the saturated gas should have been 150°F, whereas the observed inlet gas temperature varied between 156 and 157°F. However, visual examination of the coolers before and after cleaning validated the computation. In normal operation, the upper tube sheet and first several inches of the tubes showed selective signs of sulfur or dirt deposition. This was attributed to the fact that the cooling surface, although at a lower temperature than the dew point of the mixture, was not flushed effectively by the condensate.

In the tables, the gas rates of all but Item (6) of Table 2, were obtained from direct measurement. Item (6) was obtained stoichiometrically from an SO_2 balance on the system. Gas heat loads checked the water heat loads with a constant deviation of −8%. Computations of performance were carried out employing the deficient gas rate, since this approach introduces a conservative method of evaluating the analogy.

Table 1. Tests.

Run No.	No. of Exchangers Involved: Gas in Tubes	Water in Shell
1*	6	6
2	4	6
3	4	4
4	5	5
5	5	6
6*	6	6

* Normal operation.

Calculations and results

Since the gas distribution among the individual parallel units was unknown, weighted outlet temperatures were used. The gas properties, such as the specific heats, viscosities, and conductivities were taken as being constant at the average stream tem-

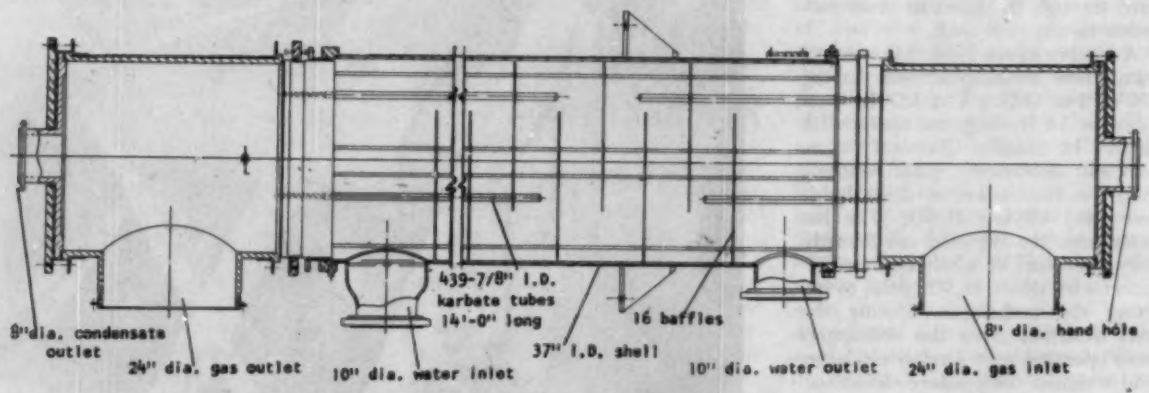

Figure 2. Outline drawing of bundles.

perature, since the temperature ranges for the vapor-gas streams were relatively small. Heat of solution, representing about 0.1 of 1% of the total heat loads were computed but otherwise neglected.

The changes in the vapor-gas properties with changes in composition were computed on a weight basis for all but the diffusivity of water vapor. The diffusivity was calculated from the formula given by Treybal (17). Since the quantity $(\mu/\rho k_d)^{2/3}$ was practically constant from point to point, only a single value was employed throughout.

The method of computation followed the trial-and-error, and graphical integration outlined by Colburn and Hougen, employing the inlet and outlet conditions plus five intermediate points for each run. No other assumptions or simplifications were used, except that the mixtures contained 6 to 7°F of superheat. The equation for simultaneous heat and mass transfer employed was

$$h_G(T_G-T_C)+K_G M_V \lambda(p_V-p_C) = h_{wl}(T_C-t_W)=U(T_G-t_W) \quad (1)$$

The connecting equation between heat and mass transfer made possible by the analogy was

$$K_G = \frac{h_G\ (c\mu/k)^{2/3}}{cp_{gf}M_m\ (\mu/\rho k_d)^{2/3}} \quad (2)$$

in which h_G, the vapor-gas convection coefficient, was evaluated by the equation of Sieder and Tate (14). The shell-side water coefficient was evaluated by the graph of Kern (9). The results are shown in Table 6.

Conclusions

While the scant prior data obtained on a single tube indicated that the Colburn and Hougen analysis and calculation method were slightly on the conservative side, this is not borne out entirely by the large-scale tests. The computed surface proved to be less than the surface actually used and required in each case. Since the gas side rate and heat balance were deficient by 8.0%, raising these to 100% would eliminate some of the deviation.

It is of greater concern that the higher the inlet velocity of the vapor-gas mixture, the greater the deviation. Since the tests at the higher velocities were carried out with pressure drops of only 12.2 in. and 13.0 in. H_2O, respectively, there is an indication that a typical compressor-intercooler, expending as much as 1, 2, or 5

continued

Table 2. Overall data.

Run No.		1	2	3	4	5	6
(1) Gas temp., °F	– In	156	156	156	157	157	157
(2)	– Out	103	108	106	105	107	104
(3) Water temp., °F	– In	84	83	84	85	85	86
(4)	– Out	(See Table 3.)					
(5) Total water rate GPM		4590	3094	3904	4237	3774	4516
(6) Total dry gas rate, mols/hr.		5290	5090	4670	5050	5290	5290
(7) Static pressure–Gas in, in. H_2O		−20.5	−19.3	−19.2	−20.0	−20.0	−20.7
(8) – Gas out, in. H_2O		−26.3	−31.5	−32.2	−28.7	−28.7	−27.0

Table 3. Individual exit gas temperatures, °F.

Run No.	1	2	3	4	5	6
Cooler A*	105	111	107	106	109	106
B	102	106	104	104	105	104
C	103	–	–	–	–	106
D	101	–	–	104	105	103
E	101	107	104	103	105	103
F	100	105	103	102	103	102

Table 4. Individual exit water temperatures, °F.

Run No.	1	2	3	4	5	6
Cooler A	99.7	104.4	99.5	101.2	103.8	102.3
B	99.0	103.8	98.6	100.4	103.0	101.2
C	99.0	–	–	–	–	101.3
D	100.0	–	–	101.8	104.0	102.3
E	97.0	100.8	97.0	98.2	100.5	99.0
F	97.0	101.5	99.0	98.8	101.0	99.5

Table 5. Individual water rates, GPM.

Run No.	1	2	3	4	5	6
Cooler A	670	670	915	762	670	670
B	692	692	953	802	707	707
C	742	–	–	–	–	742
D	749	–	–	898	782	782
E	851	851	1110	942	833	833
F	886	881	920	833	782	782
Totals	4590	3094	3904	4237	3774	4516

* Cooler positions run from left to right at bottom of Figure 1.

Table 6. Computed and actual clean performance.

Run No.	Heat Load Btu./hr.	Surface Computed by C&H*	Surface Actual	U Computed by C&H	U Actual	Surface Ratio C&H/Actual
1	30,800,000	11,826	12,050	60.0	59.0	0.98
2	27,600,000	7,315	8,032	96.4	87.9	0.91
3	26,000,000	7,412	8,032	81.4	75.1	0.92
4	29,300,000	9,500	10,040	72.2	68.2	0.95
5	30,000,000	9,660	10,040	73.2	70.4	0.96

* Lit. Cited (6).

Table 7. Computed fouled performance.

Run No.	Clean Surface Actual	$R_d = 0.002$ Fouled Surface C&H	PHT**	U Dirty Computed C&H	PHT	Surface Ratio C&H/act.	PHT/act.
1	12,050	12,865	13,280	55.2	53.5	1.07	1.10
2	8,032	8,506	8,750	83.0	80.7	1.06	1.09
3	8,032	8,524	8,630	70.8	69.9	1.06	1.08
4	10,040	10,190	10,900	67.4	63.0	1.01	1.09
5	10,040	11,733	11,080	60.3	63.9	1.17	1.10

** Lit. Cited (8).

Analogy

continued

lb./sq. in. allowable pressure drop, may introduce a still greater error. All of the single-tube data were undoubtedly obtained at even smaller pressure drops than those reported in Table 2. Experimental deviations indicated here reflect the maldistribution of the mixture through the tubes of each exchanger and also resulting from the parallel manifolding of the exchangers off the gas main.

The comparison so far has considered the Colburn and Hougen analysis as a means of predicting performance in a clean exchanger. The agreement of the experimental results with those predicted by the analogy are quite unusual, since several of the assumptions in the analogy are questionable and theoretically establish it as a conservative method for computing clean equipment. One of the questionable aspects of the mechanism lies in the fact that Colburn and Hougen considered an equilibrium to exist at any cross section such that the condensate on the wall, by virtue of the heat balance, was never subcooled. In various industrial observations the condensate has been known to leave at a lower temperature than the dew point of the outlet mixture, although this point could not be studied quantitatively in these tests. In addition, Colburn and Hougen considered diffusion to be completely independent of any temperature gradient between the vapor and the condensate—a point which would appear most conservative at large temperature differences due to thermal diffusion.

In the design of exchangers for dirty conditions, Colburn and Hougen included the resistance of the dirt for both the vapor and water in the value of h_{oi} when preparing values for graphical integration. By surrounding the tube with a dirt resistance prior to graphical integration, the condensate on the dirty tube surface will be at a higher temperature for a given over-all temperature difference, and the back pressure of the condensate will also be higher, thereby reducing the diffusion potential and increasing the total required surface.

Exception has been taken by Kern (*8, 10*) to this use of the fouling factor as an element of design in the computation method established by Colburn and Hougen to supplement their analysis. When a length of tube is continuously subjected to a combined heat and mass transfer coefficient of, say, 750 Btu./(hr.) (sq. ft.) (°F) for a steam-air mixture at the condenser-cooler inlet and a combined coefficient of as little as 5 to 15 Btu./(hr.) (sq. ft.) (°F) at the outlet, the effectiveness of a fixed fouling factor to produce oversurface is somewhat questionable. Near the inlet, where most of the heat is transferred, the fixed fouling factor may contribute a significant resistance; and approaching the outlet, where more surface is required per Btu. removed, the same fouling factor will be insignificant.

Thus, a system operating in a range of relatively low dew-points receives little or no protection against dirt as the result of a fixed fouling factor, while one operating in a range of relatively high dew-points and correspondingly high condensing coefficients would carry excessive overdesign. In the design modification of condenser-coolers suggested by Kern, oversurface was stabilized by carrying out the graphical integration on the basis of the clean over-all coefficients between inlet and outlet. The design coefficient was then obtained by adding the desired fouling factor to the reciprocal of the weighted clean over-all coefficient for the entire unit.

The literature does not disclose the relative influence of these two methods upon the design of the final unit. Table 7 is a comparison of condenser-coolers designed on the basis of the experimental data with a 0.002 (hr.) (sq. ft.) (°F)/Btu. dirt factor as treated by Colburn and Hougen (*6*) and Kern (*8*). Adding the fouling factor to the weighted clean over-all coefficient for the five tests, gives a required dirty surface ranging from 108 to 110% over the actual clean surface employed. Colburn and Hougen's method reflects the large variation in oversurface inherent in their method of treating fouling factors ranging from 101 to 117% of the clean surface.

ACKNOWLEDGMENT

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NOTATION

- c = specific heat of vapor-gas mixture, Btu./(lb.) (°F)
- h_G = gas-side heat transfer coefficient, Btu./(hr.) (sq. ft.) (°F)
- h_{oi} = combined water and tube metal coefficient for a clean exchanger, Btu./(hr.) (sq. ft.) (°F)
- k = thermal conductivity of vapor-gas mixture, Btu./(hr.) (sq. ft.) (°F/ft.)
- k_g = diffusivity of mixture, sq. ft./hr.
- K_G = mass diffusion coefficient, mol/(hr.) (sq. ft.) (atm.)
- M_m = molecular weight of vapor-gas mixture, dimensionless
- M_V = molecular weight of vapor, dimensionless
- p_c = partial pressure of vapor at condensate film, atm.
- p_{gf} = log mean pressure difference of the inert gas, atm.
- p_V = partial pressure of vapor in the gas body, atm.
- t_W = temperature of water, °F
- T_G = temperature of gas body, °F.
- T_C = temperature of condensate, °F
- U = Over-all coefficient of heat transfer, Btu./(hr.)(sq. ft.)(°F)
- λ = latent heat of vaporization, Btu./lb.
- μ = viscosity, lb./(ft.) (hr.)
- ρ = density, lb./(cu. ft.)

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Organizing heat exchanger programs on digital computers

photo courtesy I.B.M.

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Shortly after the emergence of digital computers, programs were developed for design of shell-and-tube heat exchangers. One of the early developments was reported by Kellogg Company (*1*) using a CPC computer. As the memory storage capacity and the computer speed were increased, more sophisticated programs were devised, incorporating sensitive, experience-based decisions. Reports of this developmental stage include Alco (*2*) and Esso Research and Engineering Company (*3*), both using an IBM 650

HEAT TRANSFER

computer, and the latest report by duPont (*4*) using a Univac I.

These programs covered only a limited portion of the numerous variations of heat exchanger problems. The inevitable trend in the development is toward greater completeness and versatility.

The various types of heat exchanger calculations, as they will be encountered in the process industries, are:

1. Construction
   a. Shell-and-tube exchangers, with or without segmental flow baffles. The tubes can be plain or have radially-finned surface.
   b. Double-pipe (hairpin) units or similarly constructed multiple-tube units without baffles, equipped with plain or longitudinally-finned tubes.
   c. Air coolers with high helical fins.
2. Type of operation
   a. Heat exchange without phase change i.e., between liquids or gases.

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Digital computers

continued

b. Condensation of vapors which can be total condensation and can include some desuperheating or subcooling or both. Condensation can be inside or outside tubes and with tubes horizontally or vertically located.

c. Condensation of vapor-gas mixtures (partial condensers), also as desuperheaters and subcoolers.

d. Vaporization and reboilers.

3. Problem formulation

a. Design of new equipment according to engineering specifications and respecting all applicable constructional standards and manufacturing practices.

b. If some specifications (e.g. pressure drop) are relaxed, the problem is then to find the most economical solution possible.

c. Performance evaluation of an equipment unit of known dimensions.

Almost all combinations of these variations are possible, resulting in a great number of particular solution methods required. For an engineer well trained in this type of calculation, it is a matter of judgment and experience to select the right approach. Using conventional methods of calculation for programming such a large variety of cases would result in prohibitive length and complications. Therefore, a study was made of the economically justifiable extent of programming completeness and methods of proper engineering analysis, suitable for computer use.

Economic aspects

The economics of the computer use for heat exchange equipment must be considered from several points:

1. Program completeness vs. the initial cost of development. The underlying philosophy is that the integral savings resulting from computer use vs. manual calculation must pay for the development cost within a desired amortization period. While it must be stressed that the program should permit an easy incorporation of changes due to improved knowledge of the processes, the over-all logic is unlikely to be affected in a foreseeable future. The practical limits of program completeness are found where the imponderable fineness of engineering judgment becomes irreplaceable by the computer speed.

   Besides these strictly financial considerations there will be other less tangible points. The more complete and automated a program is, the more efficient it will be for the engineer to use. He will spend a minimum of time confirming the applicability of his problem and preparing the required information.

2. Actual benefits derived from computer use. Optimized design of a shell-and-tube exchanger, which would require about one man-day for manual solution, is solved by magnetic drum computer in about 6 minutes and in about half a minute on high speed (core memory) computers. The manual to machine time ratio is then about 1:80 or 1:800, respectively, and will be approximately the same for all heat transfer problems. There is, however an additional time requirement for the computer calculation (say, one hour) for preparation of data and interpretation of results, which makes the effective solution time ratio less attractive, for the above case about 1:8, nearly independent of the computer speed. The longer the computation time, the less effect will the necessary data and interpretation time have, and the effective ratio will approach more closely the theoretical computing time ratio.

3. If, in very rough approximation, we consider that the computer time costs are in the same proportion as their respective speeds, then the direct computer charge for a problem solution will be independent of the computer type used. For design of a shell-and-tube exchanger at the current renting prices for typical computers, it would amount to about $3.00 per case solution. At first this may seem a substantial saving as against manual calculation, however, to

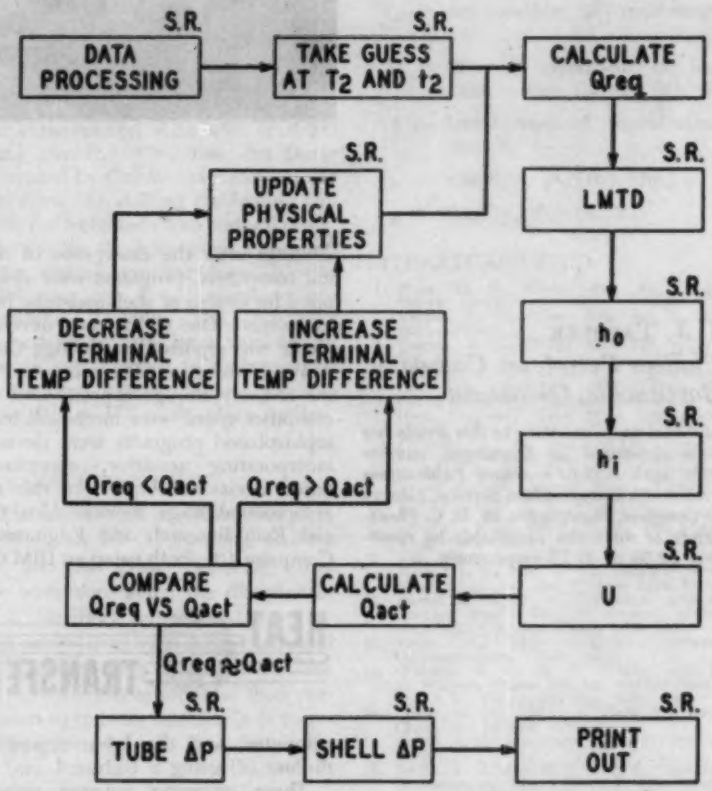

Figure 1. Executive routine example. For a given heat exchanger calculate both outlet temperatures.

this amount must be added the proportional charge for the initial development, current supervision, auxiliary services and the preparation of data, and interpretation of the results. The over-all cost of a problem solution will be further increased by the fact, that having the computer available, the engineer will investigate his problem for several solution possibilities, which he may not have done by manual calculations. It is the opinion of the writer that this is the primary benefit of computer use for heat exchanger calculations, aside from the benefit of increased speed of process evaluation. On the other hand, considering the integral cost of a computer solution, the direct saving in terms of money or manpower will be of secondary importance.

4. Requirements of computing equipment. It has been established for heat exchanger calculation problems, that the computer speed is of secondary importance, and any modern computer will be suitable. On the other hand, the size of the addressable memory (magnetic drum or cores), or the availability of an auxiliary memory (magnetic tapes) will be a factor which will decide the suitability of any computer and the possible degree of completeness of the program.

On computers of limited size the memory space will be at a premium and the program will have to be specialized to each particular case and confined to essentials. Specialized programs, however, mean more programming and checkout time. If ample memory space is available, the program will be rather generalized and elaborate features can be introduced such as: check for correct data supply to eliminate later calculation interruptions; automatic supplementing of physical constants and fluid properties; optional choice of various parameters, etc.

It should also be noted that any calculation of economic optimum depends on the ability to estimate the price of the equipment calculated. The price estimation programs are, however, quite lengthy. For this reason the economic optimization type program will be feasible only on the larger computers (4000 memory cells with magnetic tapes or larger). Following is a brief survey of the applicability of the typical computer sizes available:

a. The 2000-cell memory class computer will be capable of handling only simplified, specialized (*i.e.* non-general) programs. However the availability of magnetic tape should be helpful.
b. The 4000-cell memory class computer will be capable of handling an average specialized program. It will be helpful if magnetic tapes are available, and in that case general type programs with a medium degree of completeness can be handled successfully.
c. The ideal memory size is upward of 12,000 cells with two magnetic tapes available, in which case any type of general heat exchanger program can be handled efficiently.

Engineering analysis

The methods of manual problem solution will have to be modified to suit the techniques of computer logic. The differences can be summarized in two main items:

1. All computing operations and logical decisions, even those based on engineering experience, must be converted into equations, no matter how complicated.
2. The ingenuity of the proper attack on a problem by manual methods must be replaced by the computer speed.

Current literature has not yet been geared to the computer era and very little information of computer solution techniques has been published. Some of the outstanding requirements are:

1. The literature emphasizes graphical solutions and shortcut methods aimed to facilitate numerical calculations, often at the cost of accuracy and clarity of the physical processes involved. For computer use, information in this form is of little value and must be translated into equation form, curve-fitted, or completely new solutions must be found.

   Another characteristic procedure for manual solutions is the use of tabular information which, only in exceptional cases, is practical for computer use. A typical example is the table of shell diameter vs. tube count, which for computer use must be converted into equation form with tube diameter, tube passes, and layout pattern as parameters.
2. There is a further tendency in the literature to simplify equations by limiting them to certain specific conditions. This is acceptable for manual calculations, where the engineer is at liberty to find in his references the proper equation for each case and to check its applicability. Not so in computer usage! Each new case requires separate coding and decision making, taking costly space in the computer memory and extending the problem complexity, coding length, and checkout time.

   When the goal is a program of high degree of completeness and applicability, emphasis must be directed to development of equations with the highest degree of general validity. To demonstrate what can be achieved in this respect, development of several generalized equations is shown in the Appendix*. For example, a single equation was developed, which is valid for the condensation coefficient inside and outside tubes, horizontal and vertical condensers, and plain or radially finned tubes. In this manner, one subroutine will handle all the calculation types, which otherwise would have resulted in prohibitive complications.
3. In manual calculations the engineer has freedom of decision on questions of marginal acceptability. For example, if the specified pressure drop is exceeded *only slightly* for an otherwise good solution, he may decide to accept it. The computer program, however, is rigid and the logic behind the relaxation of given conditions for such marginal cases is prohibitively complicated. For these reasons, the most efficient combination of the engineer-computer team appears to be a system in which the computer first evaluates the economic optimum free of restrictions. The engineer then has a chance to consider how his process conditions fit into such optimum. Adjusting his data, if necessary, the engineer lets the computer

* *Appendix deposited in ADI.* *See page 45.*

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perform the final design in the second run, assuring an over-all optimum between the theoretical considerations and the engineering preference.

Program organization

Upon analyzing the solution methods for various heat exchanger problems it will be noted that certain calculation groups are repeated in basically identical form. For example, essentially the same calculations of heat transfer coefficient and pressure drop are used for new equipment design, performance evaluation of existing units, or various types of economic optimization calculations. Instead of repeating the coding of such sections, the common calculation groups are formed into *subroutines*. Subroutines are self-contained sections of computer program, which can be entered at any point of the program and will, after completion of their function, return automatically to the particular location of the program, whence they were called.

Such subroutines form building blocks which can be properly arranged for each desired type of case solution.

The overall logic of each solution is programmed in what may be called "Executive Routine." This routine directs the over-all strategy of a solution and is used only for decision making, selecting the use of various subroutines, and performing short, non-repetitive calculations. It also keeps the over-all calculation progress under constant control. (Figure 1).

The advantages of this functional division can be summarized:

a. The subroutines perform multiple functions while they need to be coded only once.
b. Eventual changes in various calculation sections (*i.e.*, subroutines) can be made without affecting the rest of the program.
c. The executive routine method makes it possible to reduce any complicated, lengthy calculation into a short, easily surveyable system. Any number of over-all solution types can then be compiled with reduced coding effort.
d. Division into subroutines is particularly important on machines with limited storage capacity. Only such portions of the over-all program are kept in the memory as are needed simultaneously for the calculation and then overstored from magnetic tapes. This system has been applied with success on a medium size computer (Datatron). However, the division is also utilized with advantage on machines with a larger memory storage (IBM 709), as complete *programmed blocks* can be compiled as precoded portions into any type of general program.

The development of a good program must not be confined to proper use of the engineering aspects but must consider the requirements of the engineer-user. This is manifested by very careful design of the data sheets and by selection of a number of optional parameters.

The over-all organization of a general and rather elaborate program for an IBM 709 is described as an example.

The program consists of:

1. A complex Data Processing Subroutine. In the first part of this subroutine a Data File will automatically supply all the physical properties required for heat transfer calculations in the form of equations which are functions of temperature and pressure. From these equations the program evaluates the properties in question for any temperature or pressure condition necessary in the course of calculation. A composite stream of up to five components can be handled and the weighted properties of the mixture calculated. This method results in a high degree of accuracy and consistency, which otherwise would be very difficult to obtain from fixed, manually supplied data. The Data File will eventually contain all frequently used fluids: water, steam, common gases, and many hydrocarbon liquids and vapors. It is estimated that this method will cover 80% of all calculations. Provisions must be made, so that the use of the Data File is only optional, and that data of fluids not included in the File can be substituted. Any combination of Data File and manual substitutions can be handled. Further, the Data Processing Routine checks all data for their existence and proper degree of magnitudes, thus preventing calculations from being started if data sheets were filled out improperly, or errors made in card punching. Errors found will be identified by proper printout, which will facilitate subsequent corrections. It is estimated that these checks will eliminate 95% of all unforeseen computation interruptions, thus contributing to a high efficiency of the computer time usage.
2. Program selection routine, which automatically selects the required program.
3. The actual calculation performing subroutines and the calculation directing executive routines.
4. Printout Subroutine.

Conclusion

It can be safely predicted that the use of digital computers for heat exchanger design and evaluation is bound to increase and will eventually become universal as the availability of efficient computers increases. The resulting effects should become apparent through greatly increased calculation speed, removing bottlenecks at times of high construction activity, optimization of designs and basic decisions on the economics of heat exchange (*e.g.*, water cooling vs. air cooling) which are impractical by manual calculations, and uniformity of calculation methods in a company. Far from devaluating the job of the engineer, the computer as a very complicated tool, will place higher demands on his basic knowledge and originality of judgment in properly evaluating the results. The high speed of calculations will make it possible for new approaches and basic considerations to receive more attention and assume more significance as a result of the improved methods for evaluating and understanding heat transfer problems. The cost of the initial program development could be substantially decreased if more attention were given in the pertinent literature to calculation techniques suitable for computer usage. This tendency could eventually be projected even further and may have influence on the future formulations of college courses.

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... *the effect of* Electrolytic gas evolution on heat transfer

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Studies of the mechanism of boiling heat transfer are seriously hampered by the fact that the heating surface temperature is usually the only controllable variable. To overcome this problem, the authors tried to produce synthetic boiling in which bubble evolution could be controlled independently of the surface temperature. Bubbles were produced electrolytically on a heated surface immersed in a dilute aqueous electrolyte. This allowed varying the rate of bubble generation by control of the electrolytic current separately from variations of the heat supply to the surface.

In boiling, the effects of increasing the temperature of the heating surface are to increase the rate of bubble evolution, the number of bubble nucleation sites, and the temperature difference between the surface and the boiling liquid. Electrolytic generation of bubbles makes the first two effects the result of the electrolytic potential rather than of temperature.

It is not proposed that synthetic boiling is identical with actual nucleate boiling, but it offers possibilities of a better understanding of the mechanism by which heat is transferred.

Literature in the field of boiling has been extensive and recent reviews have discussed the principal articles (*10, 11*). A number of investigators (*1, 4, 5, 8*) have reported enhancement of heat-transfer rates resulting from film disturbance. The work reported herein was undertaken to examine heat-transfer enhancement resulting from artificially controlled bubble generation in both natural convective and surface boiling environments.

Procedure

The bath was filled to the desired level with electrolyte and then boiled vigorously for a few minutes to deaerate it. Coolant was then circulated through the cooling coil until the desired bath temperature was obtained. For studies with natural convection heat transfer (*i.e.*, with the surface temperature below the electrolyte boiling point), the entire bath was cooled to about 35°F, and sometimes a light layer of ice was allowed to form on the cooling coil. This was done to provide a sizeable heat reservoir so that the effects of electrolytic bubble generation on natural convective heat transfer could be studied over a wide range of nearly constant temperature differences. It was usually possible, in these cases, to maintain the bath temperature below about 50°F throughout that portion of the run corresponding to natural convection with superimposed electrolytic action. Under operating conditions corresponding to surface boiling with superimposed electrolytic action, the bath temperature was maintained, in most cases, in the range from 80 to about 100°F.

After the bath had been brought to the desired temperature, the current in the electrolytic circuit was turned on and adjusted to the desired value, generating hydrogen bubbles on the surface of the copper block (see Apparatus, page 50). Power was supplied to the heater and after the establishment of steady-state conditions, data were recorded on the power supplied, the bath temperature, the metal surface temperature, and the current through

the electrolytic circuit. The operating conditions were then changed and the recording of data was repeated.

Results

The effect of electrolytic bubble generation on natural convective heat transfer is shown in Figure 4. The lower curve is that obtained in the absence of bubble generation, or for undisturbed natural convection. The tendency toward higher heat fluxes corresponding to temperature differences in the neighborhood of 180°F results from the onset of surface boiling action. It can be seen that an increase in bubble current, or in the volume of gas liberated, results in a corresponding increase in the attainable heat flux for a given temperature difference. It appears, in addition, that a major enhancement of

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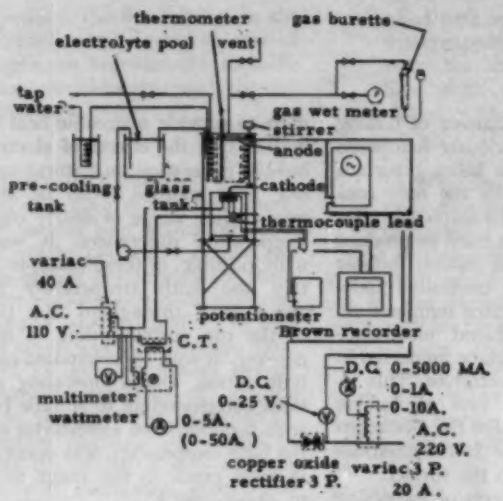

Figure 1. Overall layout of apparatus for heat transfer measurements.

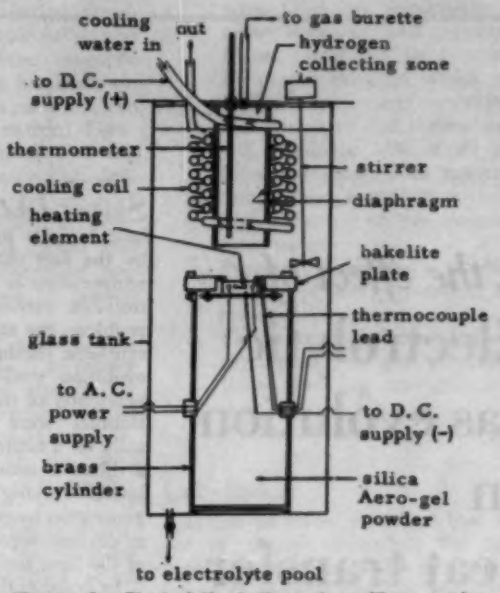

Figure 3. Electrolytic bath and auxiliary equipment.

Apparatus

A schematic diagram of the apparatus is given in Figure 1. Basically it consisted of an electrically heated copper block immersed in a dilute aqueous electrolyte. The block was used as a cathode so that bubbles of hydrogen could be generated on the heated surface by the application of an electrolytic current. The heated surface was one face of a 2-in. x 2-in. x ¾-in. block of 99.9% pure copper. Four equally spaced holes drilled parallel to the 2-in. x 2-in. faces of the block, accommodated the resistance elements, Figure 2.

The electrolytic circuit consisted of an electrolytic bath and current measuring and D.C. control equipment. The positive output terminal was connected to the cooling coil in the bath proper, and the negative terminal to the surface of the heating block. The bath was a 9-in. x 10¾-in. x 24-in. high glass tank which held 30 liters of dilute* aqueous NaOH electrolyte. The copper heating block was fitted to a square opening in the bottom of the tank so that an area of 2.64 sq. in. was in contact with the electrolyte. All portions of the block not in contact with the electrolyte were insulated with either glass wool or Aerogel thermal insulation to minimize heat losses from the heated block.

Preliminary tests made on the equipment without liquid in contact with the block indicated that heat losses were negligible compared to the heat fluxes obtainable under experimental conditions. It was expected that some heat would be transferred from the block to the liquid by conduction through the gasket and the Bakelite end plate, but this quantity of heat was estimated to be insignificant.

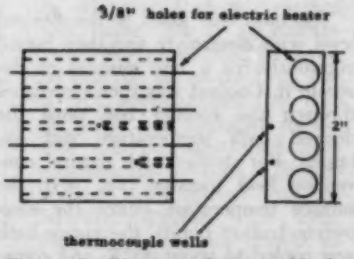

Figure 2. Diagram of copper block.

The bath was equipped with a cooling coil of about 20 ft. of ¾-in. copper tubing. Coolant (either cold water or refrigerated methanol-ice solution, depending on the temperature range desired), could be circulated through this cooling coil, which also served as the anode in the electrolytic circuit. Additional equipment consisted of a wet-test meter or, in some cases, a gas burette arranged to collect the liberated hydrogen gas so that current efficiencies in the electrolytic circuit could be measured.

Bath temperatures were measured with a standard immersion mercury thermometer. Temperatures of the heated block were measured by two copper-constantan thermocouples located about 1/16 in. beneath the heat-transfer surface and soldered in place to insure good thermal contact, Figure 3.

* *Concentrations were 0.05 N for studies under natural convective conditions, 0.1 N and 0.5 N for studies under surface boiling conditions involving low and high current densities, respectively. All studies were made under atmospheric pressure.*

Electrolytic gas

continued

heat transfer is obtained with only light bubble formation. Although heavier bubble formation does cause a higher attainable heat flux, the effect is not so pronounced as that obtained at the very onset of the slightest bubbling action. This fact is shown strikingly in Figure 5, which is in terms of heat-transfer coefficients, rather than heat fluxes. The effect of the onset of surface boiling action is also somewhat more evident when the data are plotted in this fashion.

A cross plot of the data of Figure 4 shown in Figure 6 further illustrates the effect of electrolytic bubble generation on total attainable heat flux. The curves corresponding to the higher values of temperature difference are not straight lines, but tend to be slightly concave upward, evidencing a trend toward higher heat fluxes at high bubble current and high temperature difference. This trend probably results from the tendency of the liquid to vaporize into the hydrogen bubbles as they are formed. That is, when a bubble of hydrogen is formed, the liquid surrounding this bubble tends to vaporize into it, and thus causes the volume of gas actually liberated to be somewhat in excess of that expected from electrolytic action alone. The amount of the liquid which vaporizes is dependent upon the vapor pressure of the liquid and, hence, upon its temperature. Since, experimentally, the liquid bath could not be kept at low temperatures under conditions giving these high heat fluxes, there was apparently an appreciable tendency for liquid to vaporize into the hydrogen bubbles and an accompanying trend toward slightly higher heat fluxes.

The effect of electrolytic bubble generation on heat transfer under surface boiling conditions is much the same as that under natural convection conditions. Figures 7 and 8 demonstrate the general trends for regions of low and high current density, respectively. Throughout most of the low current density region of operation, an increase in the electrolytic current tends to enhance heat transfer. However, as the current density is increased beyond about 25 amp./sq. ft., heat fluxes drop off somewhat. This effect appears to result from a surface blanketing condition, similar to that experienced in the transition from nucleate to stable film boiling.

A small amount of data taken in the range of current densities from 50 to 150 amp./sq. ft. suggests that the mechanism of heat transfer changes somewhat at higher rates of bubble generation. An increase in the temperature difference appears less effective in increasing heat flux, *i.e.*, the characteristic slopes of q/A vs. ΔT are less. In the range of bubble current from 150 to 500 amp./sq. ft., there is slight, but inconclusive, evidence that an increase in bubble current lowers the attainable heat flux. Also, it appears from the data in Figure 8 that there will be some maximum rate of heat transmission at a temperature difference slightly in excess of 50°F. Presumably at this point, the surface will have become blanketed with electrolytic and vapor bubbles and any further attempts to increase the heat-transfer rates by increasing either the temperature difference or the electrolytic current would be futile.

The effect of agitation on heat transfer in the presence of electrolytic action was studied briefly by using a small laboratory stirrer running at medium speed and positioned near the hot surface. For relatively small electrolytic currents and low rates of power input, agitation enhances heat transfer slightly. Coefficients are in the range of 10 to 25% above those observed in the absence of agitation for current densities of the order of 0 to 150 amp./sq. ft. Under surface boiling conditions and at high current densities, agitation gave no appreciable effect on heat transfer.

continued

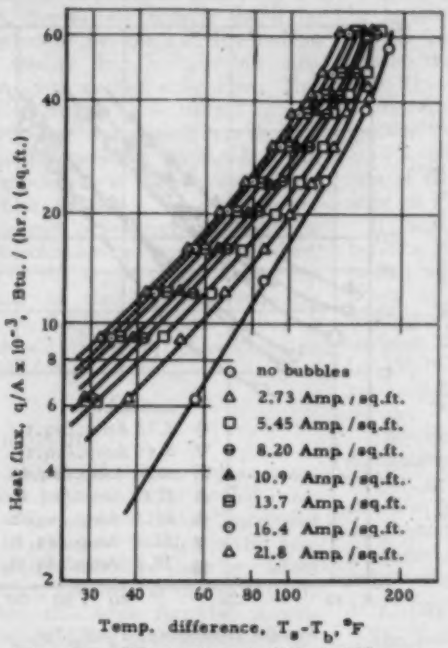

Figure 4. Effect of electrolytic bubble generation on natural convective heat transfer to NaOH.

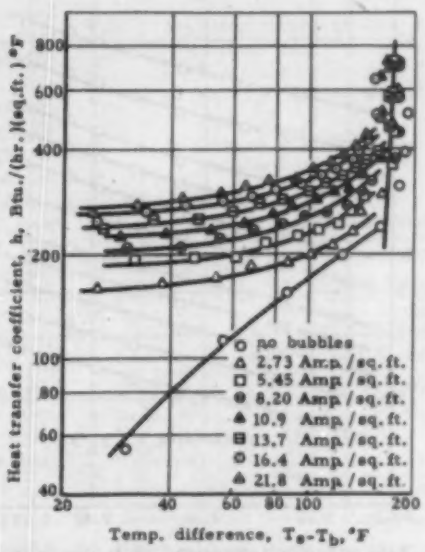

Figure 5. Effect of electrolytic bubble generation on natural convective heat transfer to NaOH.

Electrolytic gas

continued

It was noticed that the electrolytic generation of bubbles seemed to produce a larger number of nuclei than were observed under surface boiling conditions. Also, the electrolytic bubbles seemed to lack some of the violence and spontaneity of the bubbles generated by the boiling action and drifted away from the hot surface rather than collapsing. In addition, the electrolytic bubbles did not involve those latent heat effects which are inherent in boiling action. These points pose the question as to the relative effects of the generation of bubbles by boiling as opposed to the generation of bubbles by electrolytic action. Some idea of these effects may possibly be gained from speculation along the following lines of thought.

To compare the effects of the two methods for producing bubbles, some common basis must be chosen for comparison. It seems that the rate of production of gas in the form of bubbles is a significant variable common to both methods. It is desirable to know or to be able to estimate the differential heat flux attributable to bubble formation as a function of the rate of bubble formation, where the differential heat flux is that obtainable in the presence of bubbling action minus that expected under natural convection conditions at the same temperature difference.

In the case of electrolytic generation of bubbles, the experimental data yield information as to the differential heat flux as a function of the rate of bubble generation. This relationship is shown in Figure 9, which is a cross plot of data obtained from Figure 4.

In the case of the generation of bubbles by the mechanism of surface boiling, a similar relationship is more difficult to obtain. However, if the assumptions are made that:

1. A constant fraction of the differential heat flux is utilized in the production of bubbles, and
2. The latent heat of vaporization is constant, then the rate of bubble production is a linear function of the differential heat flux.

then $(q/A)_B = a(q/A)_d$ (1)

and the final expression is (2), below, at standard conditions.

The photographic evidence of Rohsenow and Clark (9) indicates that at least 1/70 of the differential heat flux is used for the formation of bubbles. Substituting, $a = 1/70$,

$$R = 0.000294(q/A)_d \quad (3)$$

or

$$(q/A)_d = 3400\,R \quad (4)$$

where the rate of bubble generation is the least that can be expected from the information given in reference (9). A logarithmic representation of this function gives a straight line having a slope of unity. This line is also shown on Figure 9 for comparison with the relationship obtained in the presence of electrolytic action.

The assumption that the enhancement of heat transfer produced by the generation of bubbles is dependent upon the number of active nuclei, or the number of bubbles, is supported by several observations reported in the literature, (3, 7). From this, it may be deduced that a decrease in surface tension causes smaller bubbles, and therefore a larger number of bubbles, to be generated for a given rate of gas evolution, thereby further enhancing the heat transfer.

The factor of bubble size might also account for the fact that the con-

(2)

$$R = \frac{(q/A)_B \text{ Btu./(hr.)} \quad \text{(sq. ft.)} \ (359 \text{ cu. ft./lb. — mole})}{(970 \text{ Btu./lb.}) \ (18 \text{ lb./lb. — mole})} = 0.0206\,(q/A)_B$$

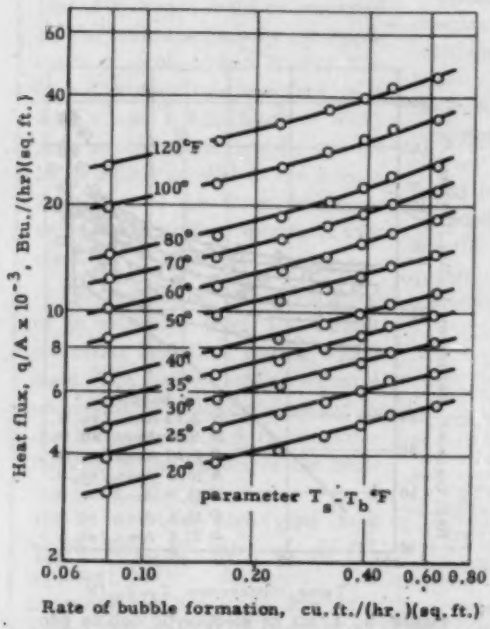

Figure 6. Effect of electrolytic bubble generation on natural convective heat transfer to NaOH.

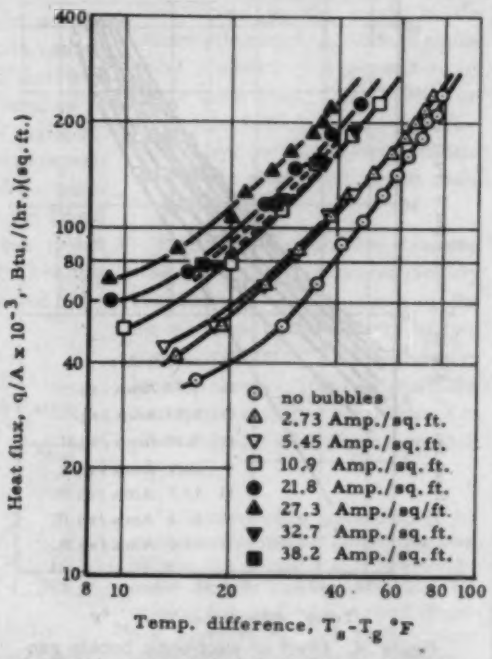

Figure 7. Effect of electrolytic bubble generation on surface boiling heat transfer (low current density range.)

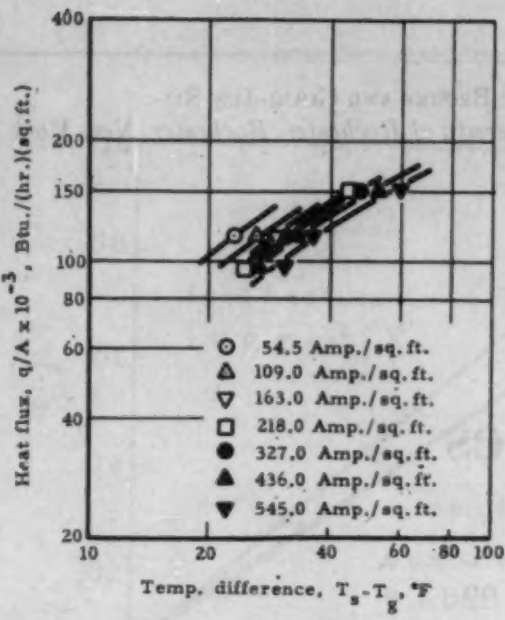

Figure 8. Effect of electrolytic bubble generation on surface boiling heat transfer (high current density range.)

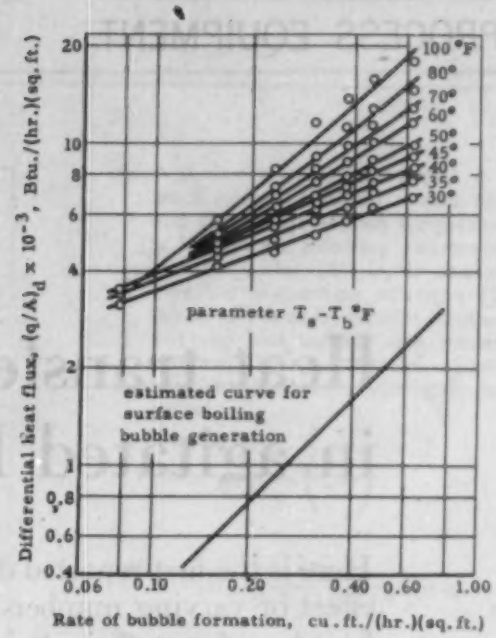

Figure 9. Effect of electrolytic bubble generation on heat transfer to NaOH.

vective temperature difference appears as a parameter in the case of the electrolytic generation of bubbles. It is seen that the higher heat fluxes are obtained in cases of high temperature differences. Since, experimentally, these high temperature differences corresponded to higher bath temperatures, the surface tension might be expected to be low and the bubble size smaller than for the low convective temperature differences. This smaller bubble size would consequently lead to a higher heat flux.

Another possible explanation for the appearance of the convective temperature difference as a parameter in the case of electrolytic bubbles is the mechanism previously described, that of the liquid in the immediate vicinity of the bubbles vaporizing into the bubbles and thus leading to high heat fluxes by enhancing the bubble formation itself.

Conclusions

It was found that an enhancement of heat transfer similar to that existing under surface boiling conditions can be obtained by electrolytic generation of bubbles. Since no latent heats are involved in the electrolytic process, this work furnishes experimental evidence that latent-heat effects are not of prime importance in the phenomenon of surface boiling, and that the high heat-transfer coefficients may be attributed to a mechanical agitation of the fluid film existing at the interface.

It was deduced that, for a given volume of gas liberated, the electrolytic process is more effective than the surface boiling process for the enhancement of heat transfer. This may be attributed to the fact that electrolytic bubbles appear to be much smaller than do surface boiling bubbles. Thus, for a given volume of gas liberated, more bubbles are formed by the method of electrolysis than by the method of boiling, and the rate of film disturbance in the presence of electrolytic action is higher.

It was observed that electrolytic bubbles lack the violent collapse of boiling bubbles. Because of the equal, if not augmented, effect of electrolytic generation of bubbles on heat transfer, it may be surmised that bubble collapse is not of major importance in the enhancement of heat transfer.

The tendency toward a surface blanketing effect, similar to that observed in the transition from nucleate to stable film boiling has been demonstrated with electrolytically generated bubbles under surface boiling conditions.

ACKNOWLEDGMENT

The authors wish to express their appreciation to the Research Corporation and to the Department of Engineering Research of North Carolina State College for financial support and encouragement.

NOTATION

A = Heat transfer area, sq. ft.
h = Heat transfer coefficient, Btu./(hr.) (sq. ft.) (°F)
q/A = Heat flux, Btu./(hr.) (sq. ft.)
$(q/A)_B$ = Heat flux producing bubbles, Btu./(hr.) (sq. ft.)
$(q/A)_d$ = Differential heat flux, Btu./(hr.) (sq. ft.)
T_s = Temperature of hot surface, °F.
T_b = Temperature of bath, °F.
T_g = Boiling temperature of bath, °F.
R = Rate of gas evolution, Btu./(hr.) (sq. ft.)

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Heat transfer in agitated kettles

Here is the first reported data for the effect of varying numbers of baffles on heat transfer coefficients in turbine agitated systems.

Heat transfer through jackets to liquids in agitated vessels is a common industrial practice. Information for the prediction of heat transfer coefficients on the kettle side of the jacket exists for unbaffled equipment. However, much discrepancy exists in the literature as to the constants of the correlation, Table 1. This work studied the effect of baffles on the kettle side film coefficients of heat transfer and compares a turbine impeller with the available literature for unbaffled systems. The fluids used provided data covering the range of Reynolds numbers from 30 to 5×10^5. Tests were of the batch type for both heating and cooling.

Equipment

The vessel used was a dish-bottom 30-gallon tank of Type 316 stainless steel with a mild steel jacket. Agitation was provided by a 6-blade, flat-bladed turbine impeller. Dimensions and geometric ratios for both tank and impeller are given in Table 2.

Piping allowed the introduction of steam and the draining of steam through a trap (to enable measurement of condensate) from the jacket drain provided on the bottom, and the introduction of cooling water through the lower jacket connection.

The agitator was driven by a ⅓ hp., 110 volt d.c. motor.

Bulk liquid temperature was measured by a thermometer at least six inches below the liquid surface and midway between the agitator shaft and kettle wall. For the more viscous solution, particularly at low impeller speeds, several temperature readings were made at varying locations.

A Hasler Speed Indicator (estimated accuracy of 2.5 r.p.m.) measured the impeller speed.

Heating was provided by 3 lb./sq.

Table 1. Summary of previous work (unbaffled equipment).

AGITATOR	REFERENCE	b^1	c^1	C^1
Flat blade	(3)	⅔	−0.14	0.40
Paddle	(2)	⅔	−0.14	0.36
Paddle	(7)	⅔	−0.24	0.415
Propeller	(1)	⅔	−0.14	0.54
Anchor	(1)	⅔	−0.14	0.45, 0.55
Anchor	(7)	⅔	−0.18	0.38[2]
2 retreating blade turbines	(3)	⅔	−0.14	0.54[4]
Turbine	(7)	⅔	−0.24	0.535
Turbine	(7)	⅔	−0.24	0.44[3]

[1] Equation of the form of Eq. 5.
[2] Turbulent range.
[3] Low position heating only.
[4] As interpreted by author.

Table 2.

Impeller diam. (L)	6 in.	
Tank diam. (D)	20 in.	$L/D = 0.30$
Liquid height (H)	21 in.	$H/D = 1.05$
Impeller height from bottom (B)	6 in.	$B/H = 0.286$
Impeller blade length (l)	1.5 in.	
Impeller blade width (w)	1.25 in.	$l/w = 1.20$
Heat transfer area (A)	10.5 sq. ft.	
Baffle width (each)	2.0 in.	
Baffle depth	Full tank depth (24 in.)	

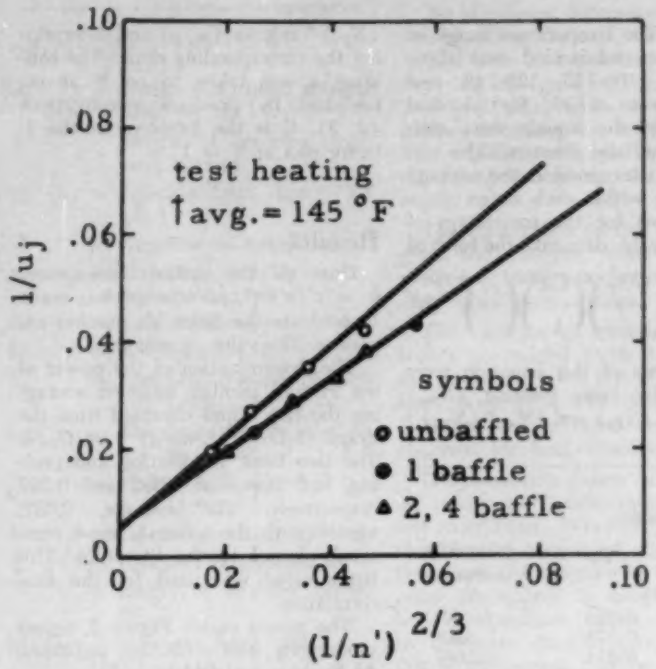

Figure 1. Comparison by test condition. (SAE 30 oil).

in. steam reduced from line pressure. The steam was assumed saturated. No air-entrainment provision was made and the data indicated that non-condensable gases entered with the steam. Cooling water from normal line sources entered the jacket at about 69°F.

The bulk fluid was weighed before being placed in the tank, and the physical properties were determined when necessary.

Procedure

Tests were made with water, S.A.E. 30 and 50 oils, and 43° Baumé corn syrup without baffles, and with one, two, and four baffles. Speeds ranged from 30 to 400 rpm for the water runs, and 100 to 450 rpm for the oil and corn syrup. The lower limit on the viscous fluids was due to insufficient mixing at speeds below 100 rpm to provide uniform bulk temperature readings. The upper limit was the speed at which there was vortex formation near the top of the impeller.

A heating and cooling run was made for each speed. The amount of condensate and rate of cooling water were measured. Power input data were recorded at the end of each cooling run. After completing the heating and cooling cycle, the speed was changed, the jacket drained of cooling water, and a new cycle begun.

In the batch system under consideration, with a constant jacket temperature, the rate of heat transfer to the bulk liquid could be described by

$$q_s = mC\frac{dt}{d\theta} = U_i A_i (T-t) + q_p \quad (1)$$

If, for a given test period θ is small compared to the overall time and the change in bulk temperature is limited, the following assumptions can be made: (1) U_i is constant over the temperature subrange; (2) the specific heat C_p remains constant; (3) the heat transfer area remains constant; (4) the rate of agitator work remains constant during the test period.

$$\text{Then: } q_s = \frac{mC}{\theta}\left(t_2-t_1\right)$$

$$= U_i A_i \frac{t_2-t_1}{\ln\left[(T-t_1)/(T-t_2)\right]} + q_p \quad (2)$$

Assuming radiation losses and the conversion of mechanical energy to sensible heat in the bulk fluid to be negligible, U_i is easily calculated. $1/U_i$, the sum of resistances (in series) to heat transfer, equals

$$\frac{1}{h_s} + r_s + r_f + \frac{1}{h_j} . \quad (3)$$

Because the jacket temperature remains constant, $1/h_s$ and r_f (assuming no scale buildup) remain constant. If the change in thermal conductivity is considered negligible over the entire test range, the jacket wall resistance is constant. Therefore, the major variability in U_i is caused by h_j, the kettle side film heat transfer coefficient.

Previous work (*1, 2, 3, 7*) in this field has established that $h_j = \phi\ (N_{Re})^{2/3}$. Assuming that, at a

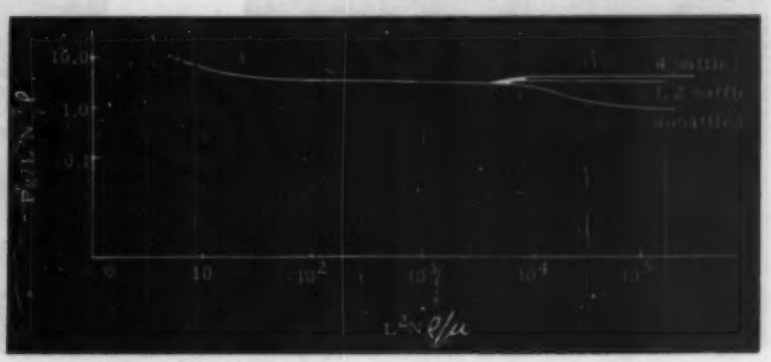

Figure 2. Power input correlation.

... the increase in turbulence when baffles are added tends to decrease the thickness of the liquid film at the kettle wall.

Agitated kettles

continued

given kettle liquid temperature, $h_j = c'(n')^{\frac{2}{3}}$ then $\frac{1}{U_i} = \frac{1}{H_s} + r_f + r_k + \frac{1}{c'(n')^{\frac{2}{3}}}$. A plot of $1/U_i$ vs. $(1/n')^{\frac{2}{3}}$ should yield a straight line with an intercept at the ordinate of $1/h_s + r_f + r_k$ and a slope of $1/c'$. This method, a modified Wilson Plot (Figure 1) for interpreting heat transfer, was used in the correlations of this work. The temperature range of the test was subdivided into three increments (100-125, 126-140, and 141-150°F) in which the physical properties of the liquids were considered essentially constant. The viscosity was determined at the average temperature within each range.

(4)

Expressions for the correlation of the heat transfer data take the form of

$$\frac{h_j D}{k} = C \left(\frac{L^2 n \rho}{\mu}\right)^a \left(\frac{C\mu}{k}\right)^b \left(\frac{\mu_j}{\mu}\right)^e \quad (5)$$

The constants of this equation were evaluated by cross plotting $(N_{Nu})(N_{Re})^{-a}$ vs. (N_{Pr}) and $(N_{Nu})(N_{Re})^{-a}(N_{Pr})^{-b}$ avg. vs. (μ_j/μ) and determining the corresponding slope. The constant a was taken to be ⅔ as established by previous investigations (2, 3). C is the intercept of the J-factor plot at $N = 1$.

Table 3. Properties of the liquids.

	Sp. Gr. 60°F/60°F	Cp_{avg}	k_{avg}	μ at 100°F centipoises
Water	from alignment chart, (4)			
S.A.E. 30 oil	0.90	0.468	0.073	90[1]
S.A.E. 50 oil	0.90	0.468	0.073	190[1]
Corn Syrup	1.4206(100°F/60°F)	0.573	0.214	12,500[2]

[1] Extrapolations made on A.S.T.M. Standard Viscosity–Temperature hart D-341.
[2] Data provided by Research Laboratory, Clinton Corn Processing Company, Clinton, Iowa.

Table 4.

Sample Data-Fluid S.A.E. 30 Oil
Test Conditions: 1 Baffle, Heating Run, $t_{avg} = 118°F$.

$\left(\frac{C\mu}{k}\right)_{118°} = 850$ $\quad \left(\frac{\mu_j}{\mu}\right)_{118°} = 0.185$

n	$1/U_i$	$(1/n')^{\frac{2}{3}}$	h_i	$h_j D/k$	N_{Re}	J
100	0.040	0.0464	28.7	655	618	55
170	0.031	0.0326	40.8	930	1050	77
250	0.024	0.0252	52.7	1205	1550	100
420	0.019	0.0178	74.5	1700	2600	141

$c' = 1.33$

Results

Due to the initial assumption, $h_j = c'(n')^{2/3}$, no attempt was made to evaluate the Reynolds number exponent. The value, ⅔, was used.

The determination of the power of the Prandtl number involved averaging the two slopes obtained from the graph $(h_j D/k)(L^2 n\rho/\mu)^{-\frac{2}{3}}$ vs. $C\mu/k$. The two lines, for heating and cooling, had slopes of 0.382 and 0.292 respectively. The average, 0.337, agreed with the value ⅓, most commonly found in the literature. This latter value was used for the final correlation.

The power curve, Figure 2, agrees moderately well with that published by Rushton and Oldshue (6).

The exponent for the viscosity ratio (Figure 3) was found to be –0.14. This value agrees with most of the literature. Here μ_j is defined as the viscosity evaluated at the jacket temperature. No change was found in the exponent of the viscosity ratio when μ_j was evaluated at the kettle wall temperature. The temperature of the wall was calculated from heat input information and evaluated heat transfer resistances. No change was observed due to the thin vessel wall (3/16 in.); the jacket temperature closely approximated that of the wall.

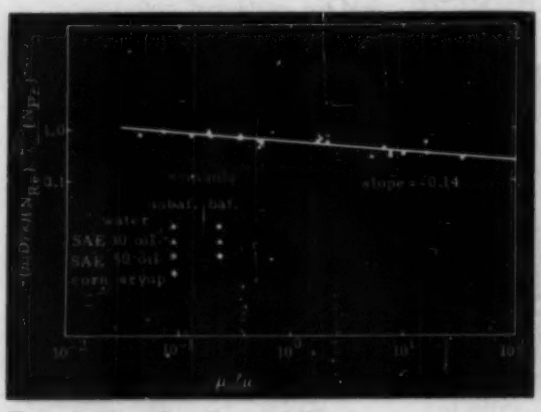

Figure 3. Viscosity ratio correlation.

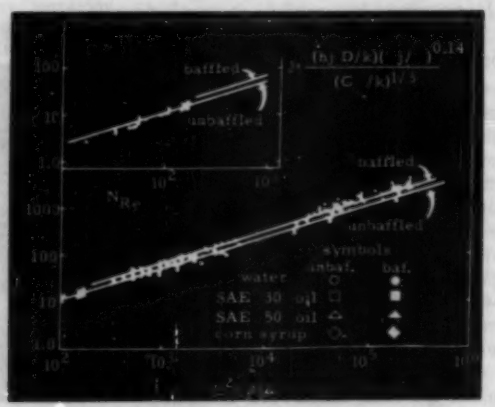

Figure 4. J factor correlation.

The final correlation of J versus N_{Re} (Figure 4) gave two distinct lines; one each for the unbaffled and baffled conditions. To evaluate the constant C, the lines were extrapolated to $N_{Re} = 1$. The constant for the unbaffled tests, $C = 0.54$, duplicates the findings of Cummings and West and Uhl for turbines (Table 1).

No significant differences were observed among the one-, two-, or four-baffled tests. Extrapolation of the baffled data line gave an intercept of $C = 0.74$. It then can be concluded that baffling increases the kettle side film heat transfer coefficient by 37%. This difference existed in the turbulent region only.

The data taken in the viscous region and in the transition range showed no difference between baffled and unbaffled conditions.

The increase in turbulence when baffles are added tends to decrease the thickness of the liquid film at the kettle wall. Thus with decreased film thickness, an increased coefficient is obtained for heat transfer.

The transition range data showed no evidence of differences between test conditions. Whether differences should exist cannot be concluded in this work. Limitations in the equipment, particularly in measurement of bulk temperature, made it difficult to duplicate data within less than 20% in this region. If, therefore, small differences do exist, they were not observable in this region.

The evaluation of the intercepts on the $1/U_i$ vs. $(1/n')^{2/3}$ graphs gives values for $1/h_s + r_f + r_k$ for heating and cooling. These values were used as fixed points on each graph once they were evaluated. The value for cooling agrees with the calculated value using $h_s = 180$ for cooling water, $k = 9.4$ for Type 316 stainless steel. Because the tank was new, r_f was considered equal to zero.

$$1/h_j = 0.00555$$
$$r_k = 0.00163$$
$$\text{Calculated total} = 0.00718$$
$$\text{Observed total} = 0.0075$$

For heating, the Wilson Plot intercept was found to be 0.005. This is high compared to the usual film resistance for condensing steam. No effort was made to remove noncondensable gases from the input steam. The presence of these gases tends to decrease the condensing film coefficient, therefore increasing the overall resistance. This may account for the high observed intercept.

Data were duplicated to within 20% for the water and corn syrup runs. All oil data were duplicated to within 5%.

Heat losses from the surface of the bulk liquid to the atmosphere (ambient temperature = 85°F) were estimated at less than 5%. These losses, which compensate for the conversion to sensible heat of mechanical energy from the agitator, are neglected.

A heat balance on the overall system yields agreement to within 20% for the heating condition and 15% for cooling.

Conclusions

Data for kettle side heat transfer film coefficients can be correlated by the following equations:

$$\frac{h_j D}{k} = 0.54 \left(\frac{L^2 n \rho}{\mu}\right)^{2/3} \left(\frac{C\mu}{k}\right)^{1/3} \left(\frac{\mu_j}{\mu}\right)^{-0.14} \quad \text{(Unbaffled)} \qquad (5a)$$

$$\frac{h_j D}{k} = 0.74 \left(\frac{L^2 n \rho}{\mu}\right)^{2/3} \left(\frac{C\mu}{k}\right)^{1/3} \left(\frac{\mu_j}{\mu}\right)^{-0.14} \quad \text{(Baffled)} \qquad (5b)$$

There is no difference in heat transfer coefficient because of additional baffling in this size vessel. Larger vessels, with much larger surface area, may show significant differences with variations in the number of baffles.

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NOTATION

- A_i = kettle side heat transfer area, sq. ft.
- B = height of impeller from tank bottom
- C, C_p = Specific heat, Btu./(°F)(lb.)
- C = Constant of correlation
- c' = line slope of $1/U_i$ vs. $(1/n')^{2/3}$ graph
- D = tank diameter, ft.
- H = liquid height, ft.
- h_j = film heat transfer coefficient, kettle side
- h_s = film heat transfer coefficient, jacket side
- J = $(h_j D/k)(C\mu/k)^{-1/3}(\mu_j/\mu)^{+0.14}$
- k = thermal conductivity
- L = diameter of impeller, ft.
- l = length of impeller blade, ft.
- LMTD = log-mean temp. diff.
- N_{Nu} = Nusselt Number = $\frac{h_j D}{k}$
- N_{Re} = Reynolds number $= L^2 n \rho/\mu$
- N_p = Power number $= pg/n^3 L^5 \rho$
- n = rotational speed impeller, 1/sec.
- n' = rotational speed impeller, 1/min.
- q_w = rate of heat input Btu/hr.
- q_p = rate of conversion of mechanical energy to sensible heat, Btu/hr.
- r_k = resistance to heat transfer by kettle wall
- r_f = resistance to heat transfer by fouling
- T = jacket temperature
- t = bulk temperature
- U_i = overall heat transfer coefficient based on heat transfer area, kettle-side
- w = width of impeller blade
- μ = viscosity based on bulk liquid temperature
- μ_j = viscosity based on jacket temperature
- ϕ = "a function of"
- ρ = bulk density
- θ = time, min.

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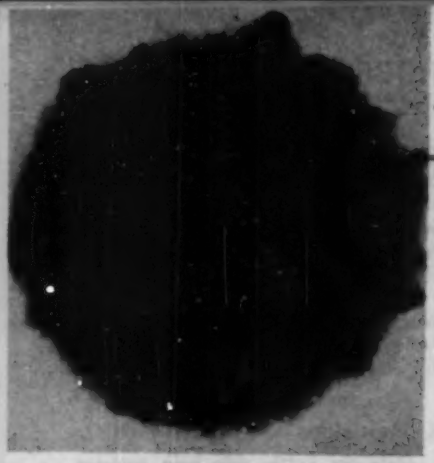

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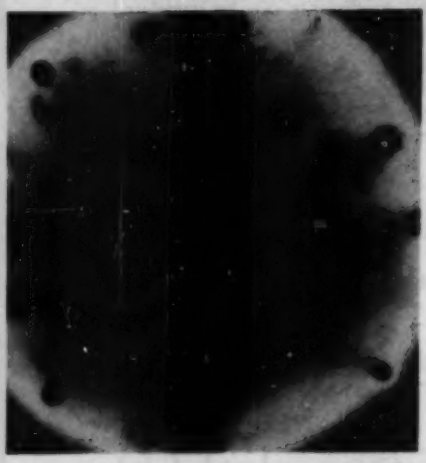

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Novel method for determining nucleate boiling sites

Counts of active bubble-producing sites were determined throughout most of the nucleate region for a boiling liquid. An aqueous solution of nickel salts containing 20% solids was boiled at atmospheric pressure on a horizontal, flat, copper surface, with no forced convection. The technique for determining active sites consisted of plating a thin layer of nickel on the copper surface during the boiling runs and subsequently counting the number of pin holes in the plate.

The heat flux was varied from 7680 to 535,000 Btu/(hr.) (sq. ft.) and the Δt from 17.3 to 218.8°F. Counts of active sites were obtained from zero to a maximum of 1130/sq. in. at 317,000 Btu/(hr.) (sq. ft.). A random geometrical distribution of active sites was revealed by a photographic study of the nickel-plated heated surface.

Nucleate boiling is characterized by the presence of unique active spots on the heat transfer surface. These sites have the ability to initiate and to support the nucleation of vapor bubbles. The nature of active sites has been demonstrated conclusively (*2, 10*). They are tiny pits and scratches, although occasionally other imperfections in the solid heat transfer surface may be active.

The rate of heat transfer from a hot solid to a boiling liquid is undoubtedly determined by the number of bubble-producing sites and the rate of vapor production at each site. As the temperature of the surface is increased above the liquid saturation temperature, the number of active sites increases and is accompanied by a simultaneous increase in the heat transfer rate. The present work was designed to determine exactly how these three items (Q/A, Δt, and N/A) are related in the absence of forced convection, for one liquid boiling on one solid, particularly over a wide range of heat fluxes. The difficult feature was the measurement of the number of active sites. A method* of simultaneous electroplating during boiling was developed successfully. This permitted counts of active sites located as dense as 1130 per square inch.

All prior counts of active sites during boiling were limited to low heat fluxes (*3, 4, 5, 8*) because a visual method of counting was employed. At high heat fluxes the number of sites is very large, the action is chaotic, and counting visually or photographically through a window becomes impossible. The present work was undertaken to explore the possibility of boiling an aqueous solution of a metal salt in contact with an anode at atmospheric pressure to see if the hot surface, the cathode, could be plated during boiling. It was expected that bubbles being generated at the active sites would produce pin holes in the

Figures 1-4. Bottom to top: Plated 2-in. boiling surface;
(1) Q/A=7680 Btu/(hr.) (sq.ft.); Δt=17.3°F; pH=4.6; N/A=0 ft.$^{-2}$.
(2) Q/A=27,900 Btu/(hr.) (sq.ft.); Δt=38.3°F; pH=4.6; N/A=489 ft.$^{-2}$.
(3) Q/A=28,900 Btu/(hr.) (sq.ft.); Δt=37.3°F; pH=1.7; N/A=1220 ft.$^{-2}$.
(4) Q/A=200,000 Btu/(hr.) (sq.ft.); Δt=47.2°F; pH=1.7; N/A=39,100 ft.$^{-2}$.

* *Deposited in ADI.*

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To measure the number of active bubble-producing sites in a boiling liquid, a method of simultaneous electroplating during boiling was developed which successfully permitted counts of active sites as dense as 1130/sq. in.

plate, and these could be counted subsequently at leisure. Such was the case.

The new counting technique permits counts far greater than the previously high record of 60 active sites per square inch recorded by Corty and Foust (*3*). The highest count reported in the present paper is 1130 per square inch. The upper limit is unknown. Unfortunately, the method is suitable only for solutions which can be used for electroplating.

Photographic study of plated surfaces

Fifty-one experimental runs were made with the heat flux varying from 7680 to 535,000 Btu./(hr.) (sq. ft.), and a change in Δt from 17.3 to 218.8°F. Counts of active sites were obtained from zero to 162,700/sq. ft. Each run was made with a newly polished surface. Some examples of the photographs of surfaces made after plating are shown in Figures 1, 2, 3 and 4. The actual area represented in the photographs is 2 square inches.

Figure 1 shows a plated surface made at a heat flux of 7680 Btu./(hr.) (sq. ft.). At this low heat flux, heat losses from the boiler made it necessary to use an auxiliary heater to maintain the temperature of the liquid at the boiling point. Since no bubbles were produced in the 1¾-in. diam. test area, free convection accounted for all the heat transfer. As a result no pinholes can be seen in the plated surface within this area. If any such pinholes had been present, they would have been confounded with active sites produced during boiling in other runs, and this would have been a serious problem.

In Figures 1-4 a faint outline of the circular junction between the heated surface and the annular fin can be traced. The amount of plating in this area is controlled by the frequency of bubble evolution, which was observed to be low at low heat fluxes, and to increase when the heat flux was raised. At least one bubble-producing site was always present there, even at the lowest heat flux. These active sites were located outside the 1¾-in. test area, and were not counted.

Around each active site in the photographs can be seen an aureole which was caused by the intermittent plating that occurred near the site after a bubble left the surface, and liquid took its place. An aureole, or pinhole, produced in this manner, was

therefore a tapered depression in the plated nickel film. The pinholes in Figure 2 (for example) were calculated to have a slope of about 0.1 degree with the horizontal. It can be seen that the diameter of these pinholes, which represents the limit of bubble expansion on the surface, decreases with an increase in heat flux. At a heat flux of 27,900 Btu/(hr.) (sq. ft.) in Figure 2, the average diameter is about 0.17 in., whereas at 200,000 Btu/(hr.) (sq. ft.) in Figure 4, the average diameter is only about 0.016 in. These dimensions are difficult to measure because the edge of the pinholes is not well defined. However, Figures 2, 3 and 4 definitely indicate that increases in the heat flux cause a decrease in the size of the bubbles at breakoff. This conclusion does not agree with prior photographic observations (*9*), which indicated that for methanol boiling on a tube, at heat fluxes up to 100,000 Btu./(hr.) (sq. ft.) the break-off diameter changed very little with the heat flux. The reason for the discrepancy is not known, however, it may have been caused by the difference in geometry of the boiling surface.

A consequence of a wave theory which Chang (*1*) has proposed for nucleate boiling is that the active sites should appear at the nodes of waves which are postulated to cover the heated surface. The theory predicts that this wavelength, and therefore the spacing of active sites, should be a function of the surface temperature. An examination of the photographs of the plated surface did not reveal any ordered geometrical pattern of active sites. At low heat fluxes boiling was quite often observed taking place in patches, but at higher fluxes the active sites were generally scattered at random.

The theory of Zuber and Tribus (*11, 12*) utilizes a different concept of wave formation for the analysis of the maximum heat flux. In this theory it is postulated that immediately before the maximum heat flux, columns

continued

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Nucleate boiling site

continued

of liquid and vapor above the heated surface are separated by a certain critical wavelength, and are geometrically arranged so that part of the surface is covered by vapor and part by liquid. Since the experimental runs were not carried to the maximum heat flux, the validity of the theory could not be tested. However, future experiments should be made with this object in mind, even if it results in a number of destructive burnouts of the heater.

Discussion of Data

The experimental relationship between heat flux and the population of active sites on the heated surface is shown in Figure 5. At populations less than 325/sq. ft., or 4 sites in the 1.77 sq. in. test area, the number of active sites was counted visually. At low heat fluxes the number of active sites did not increase smoothly, but rather in a step-wise manner. Thus, it was difficult to fix a specified number of active sites on the surface by controlling the output of the heater. All counts greater than 325 active sites/sq. ft. were obtained by the electroplating technique. At low heat fluxes some scatter of data was obtained because a low pH solution was used which caused the evolution of hydrogen on the cathode during electroplating. This gassing occurs if the solution has a pH less than 4.0 (7). In these runs the hydrogen-evolving sites became steam-producing sites. The contribution of hydrogen evolution to the number of active sites was about five or six per 1.77 sq. in. Using the same solution at higher heat fluxes, however, produced no discrepancies. This can be explained by the fact that if the contribution of hydrogen was the same at all heat fluxes, then this number of five or six is very small compared to the number of "true" active sites. The validity of this explanation was verified by runs at low and intermediate heat fluxes using a solution having a pH of 4.6. No gassing was observed on the cathode, and the data followed the experimental curve. In these runs the high pH solution gave a very shiny plated surface, whereas the low pH solution produced a dull gray surface. The latter condition was more suitable for counting the number of active sites because it gave better contrast.

The plot of the data, Figure 5, shows that the relationship between heat flux and active site population is represented by the equation:

$$Q/A = 1400\ (N/A)^{0.47} \qquad (1)$$

This is not a linear relationship, as Jakob (4) had originally proposed. The theory that each active site contributes a quantized amount to the total heat flux may be true for a specified heat flux, but the amount is not the same at all heat fluxes. This may be seen by dividing the above equation by (N/A) to obtain the heat flux per active site.

$$Q/N = 1400\ (N/A)^{-0.53} \qquad (2)$$

The amount of heat attributed to each active site becomes less as the population of active sites increases. At the beginning of boiling, although most of the heat is transferred by free convection, the first active site in the 1.77-sq. in. test area (81 sites/sq. ft.), was *associated* with 141 Btu./hr. By comparison, at a heat flux of 317,000 Btu./(hr.)(sq. ft.) each active site was *associated* with only 1.95 Btu./hr.

To compare the above data with previous data obtained for water boiling on a horizontal surface, the experimental results of several other investigators are plotted in Figure 5.

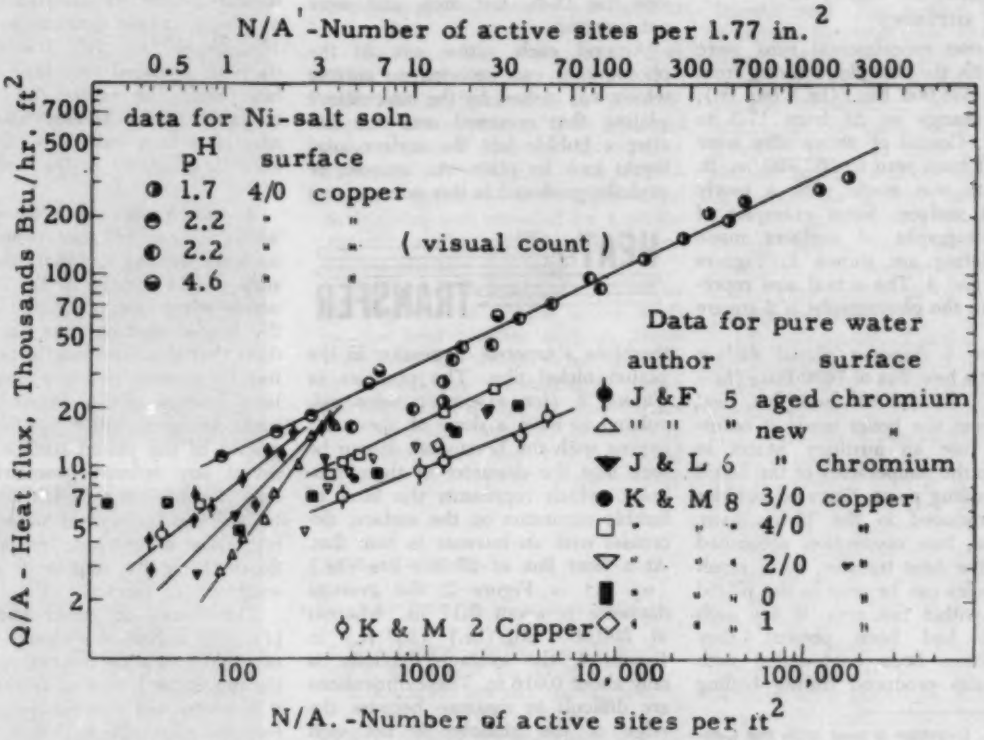

Figure 5. Heat flux as function of active site population.

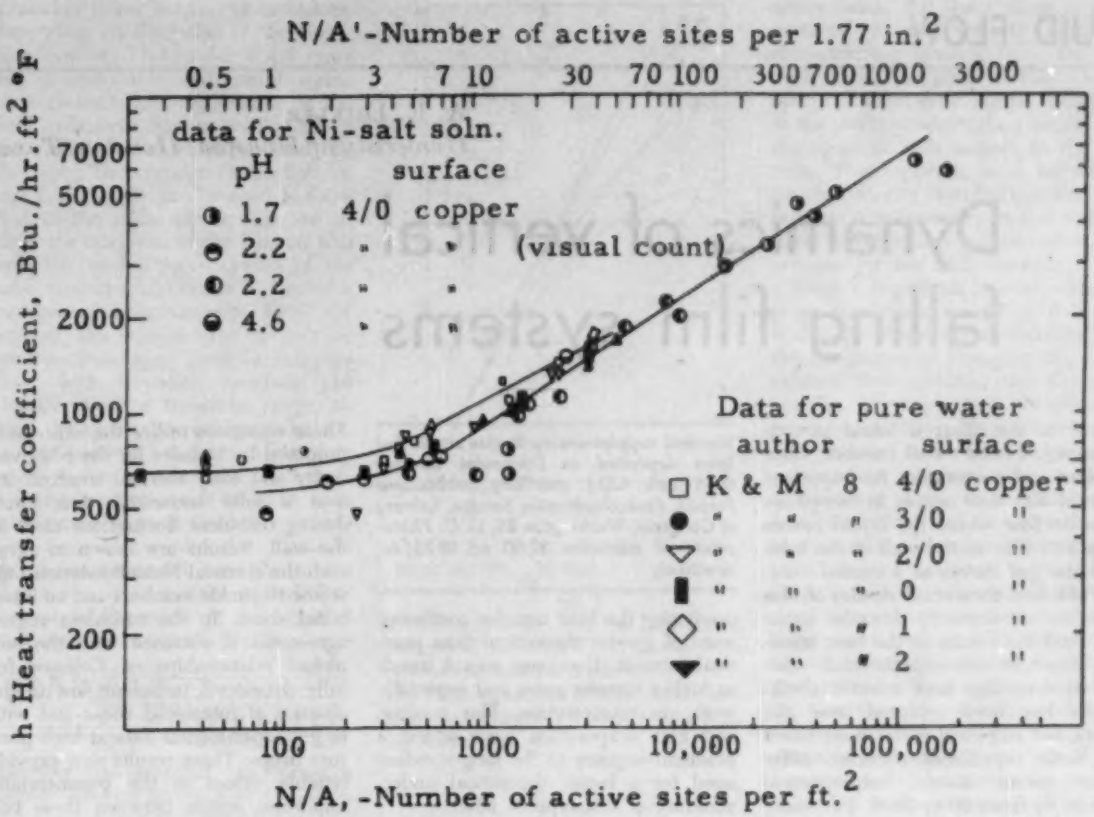

Figure 6. Heat transfer coefficient as a function of active site population.

The data of Kurihara and Myers (8) for a copper surface having different degrees of polish give a family of curves nearly parallel to that obtained for the nickel-salt solution. However, the data of Jakob and Fritz (5) and of Jakob and Linke (6) for a polished nickel surface give a different relationship. The reason for this difference may be the type of metal used for the boiling surface; however, the latter two groups of workers included active sites which occurred at the machined edge of their heated surface. There is no assurance that these behave exactly like sites on the flat area.

The population of active sites as a function of the heat transfer coefficient is plotted in Figure 6. At the lower end of the curve free convection is controlling, and the heat transfer coefficient increases very slowly as the number of active sites increases. The knee of the curve corresponds to the point where boiling becomes the principal mechanism of heat transfer. At populations greater than 500/sq. ft. the curve can be represented by the equation:

$$h = 49\ (N/A)^{0.43} \qquad (3)$$

The exponent in this equation is in the range 0.33 to 0.46 found by Nishikawa and by Kurihara and Myers.

Conclusion

Electroplating during boiling is a new tool for boiling research. The populations of active sites on a heated surface can now be determined at much greater heat fluxes than was possible by previous techniques. An analysis of information from additional experiments could lead to a unified theory for the entire range of nucleate boiling in which the surface condition, as well as nucleation and bubble growth, is treated as a variable.

NOTATION

- A = heat transfer area, sq. ft.
- A' = heat transfer test area, 1.77 sq. in.
- h = heat transfer coefficient, Btu./(hr.)(sq. ft.)(°F)
- N = number of active sites on heated surface
- Q = rate of heat transfer, Btu/hr.
- Δt = temperature-difference driving force $(t_w - t_o)$, °F.

ACKNOWLEDGMENT

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Dynamics of vertical falling film systems

Flow of thin films is found in condensers, wetted wall towers, film coolers, and evaporators. An important case of film flow occurs in two-phase annular flow where the liquid moves as a thin film on the wall of the tube and the gas moves as a central core.

Published theoretical studies of film flow do not correctly describe either the fluid mechanics or the heat transfer. Considerable experimental work on condensation heat transfer coefficients has been reported over the years, but empirical correlations based on these experimental studies differ from recent careful experimental values by from 50 to 500%. For many years even a fairly wide discrepancy made little practical difference. In conventional process equipment the resistance to heat transfer on the condensed film side was small compared to the other resistances. As a result even a sizeable error in the film side coefficient introduced only a small error in the overall resistance and heat transfer coefficient. With this situation, more accurate methods for predicting the heat transfer coefficient were of greater theoretical than practical interest. However, recent trends to higher transfer rates and especially work on transpiration, film cooling, and film evaporation have added a practical urgency to the long-standing need for a better theoretical understanding of this type of flow.

Material supplementary to this article has been deposited as Document number 6058 with A.D.I. Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. Photoprints or microfilm $7.50 or $2.75 respectively.

This article presents a theoretical study of flow and heat transfer in thin films. New equations are developed for velocity and temperature distribution in thin vertical films. These results are then used to calculate local and average heat transfer coefficients as well as local film thickness. The geometry is similar to that found in falling film evaporators, vertical condensers and film cooling equipment.

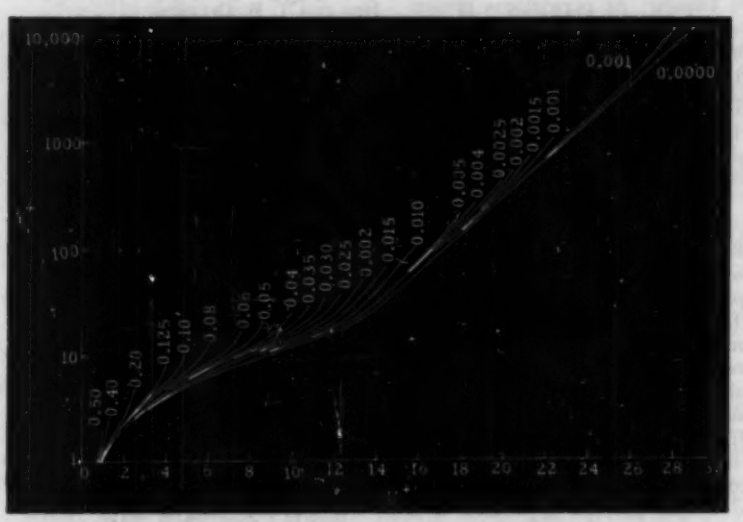

Figure 1. Universal velocity distributions for films. (Parameter is σ^3/ν.)

These equations utilize the expression proposed by Deissler for the eddy viscosity and eddy thermal conductivity near a solid boundary, thus introducing turbulent fluctuations close to the wall. Results are shown to agree with the classical Nusselt relationships at low Reynolds numbers and no interfacial shear. In the turbulent region agreement is obtained with the empirical relationships of Colburn for fully developed turbulent flow in the absence of interfacial shear and with recent experimental data at high pressure drops. These results now provide reliable values in the commercially important region between these two extremes. Due to the complexity of the mathematical forms, solutions to most of the equations were obtained on an electronic computer. These numerical results are presented graphically for Reynolds numbers from 100 to 50,000, and Prandtl numbers from 0.1 to 10.0 for a wide range of vapor loadings, and compared in detail with recent experimental data for condensing systems.

Measurements of both flow and heat transfer in the late 20's and early 30's indicated that the Nusselt relationships (*1*) were conservative, especially at higher rates of flow. Colburn (*2*) suggested a semi-theoretical relationship in 1934 to account for turbulent flow in the film. He assumed that the transition Reynolds number for the film was 2000, as it was for flow in pipes, and that there was no interfacial shear. Grigull (*3*) attempted to find a transition Reynolds number other than 2000 which, when used to predict heat transfer, would describe experiment more closely. However, none of these mentioned, as well as many others not included, presents a unified theory which covers all cases and which seems to describe experimental results.

A model for film flow

It is customary to consider flow in

a conduit either laminar or turbulent, depending on the value of the Reynolds number. This model is not exact but is reasonable and useful when, for turbulent flow, the portion of the field in laminar flow is small. Such is the case for flow when the fluid fills the pipe. The correlations of Rothfus and Prengle (*6*) can be used to show that at Reynolds numbers as low as 2500 the thickness of the laminar film near the wall is less than 5% of the tube diameter; while at a Reynolds number of approximately 1000 the laminar film occupies the entire tube cross-sectional area. Thus, for full-pipe flow, with Reynolds numbers just slightly over the transition range, almost the entire flow field is turbulent.

This concept has been assumed to apply to flow in thin films (*2, 3, 4, 7, 8*). Much effort seems to have been misdirected toward finding a transition Reynolds number for films. In the model proposed here the notion that a film is in laminar or turbulent motion is discarded. It is suggested that over the range of film Reynolds

numbers encountered in practice *neither* the size of the film section in laminar flow nor that in turbulent can be neglected. At Reynolds numbers of the order of 10,000 especially when interfacial shear exists, the film interface is still very close to the wall. As a result, a significant portion of the film thickness is in laminar motion and over much of the rest of the film, transition-type flow may occur.

Flow at a given position is considered laminar only when the shear stress and velocity gradient are linearly related. At this same position it is assumed that the heat flux is linearly related to the temperature gradient. Modern turbulence theories (*9*) suggest the existence of damped turbulent fluctuations starting at the wall. It is suggested that neither true laminar nor fully developed turbulent flow exists in the film, and any theory studying momentum and heat transfer must consider combined mechanisms *at all points in the film.*

Theory

The equations evolved in this development are, in general, too complex for analytical solution. Details of the theoretical development and tables of important numerical solutions are included in the Appendix*. We will attempt to show here the broad outlines

* Appendix available from ADI as Document No. 6058.

Figure 2. Typical velocity distributions for $Re_{Lx} = 132$.

of the approach and the significant theoretical findings. Comparison with experiment will be made later.

The basic equations which outline this problem, written for any position in the liquid film are:

$$\tau = \frac{1}{g_c}(\mu_L + \epsilon\rho_L)\frac{du}{dy} \qquad (1)$$

$$Re_{LX} = \frac{4\rho_L}{\mu_L}\int_0^m u\,dy \qquad (2)$$

$$q = -(k_L + \epsilon_H C_{PL}\,\rho_L)\frac{dt}{dy} \qquad (3)$$

Equation (1) relates the shear stress to the velocity gradient and is the "total shear equation." In the region near the wall, where the turbulence is damped and the eddy viscosity becomes small, the shear stress is proportional to the velocity gradient, characterizing laminar flow. On the other hand, the point of fully developed turbulent flow can be described as the position where the viscosity becomes small with respect to the $\epsilon\rho_L$ term. This equation must be solved for the velocity distribution. For this purpose it is necessary to find a shear stress distribution equation and an expression for the eddy viscosity.

Since it is difficult to work with the point conditions, u and y, it is desirable to relate these variables, by the integration of Equation (2), to an external flow variable, the Reynolds number. For any given velocity distribution, the Reynolds number is uniquely related to the film thickness, m.

Equations (1) and (2) are concerned only with the mechanics of flow. Equation (3) deals with the heat transfer. To solve it requires a knowledge of the eddy thermal conductivity. The techniques of the analogies are based on the assumption that, in a convective field, momentum and energy are transported by similar mechanisms. This is equivalent to saying that the eddy viscosity and eddy thermal conductivity are equal, or uniquely related. This has been demonstrated by an increasing number of studies in recent years (*10*) (*11*). In general, the values of ϵ and ϵ_H depend on position, y, and velocity, u. It is therefore necessary to obtain a solution to the velocity distribution problem before being able to proceed with the solution of the heat transfer equation. The solution yields values of temperature vs. distance. If the heat flux at the wall is then divided by the *overall temperature difference* in the direction of heat transfer, the heat transfer coefficient is obtained.

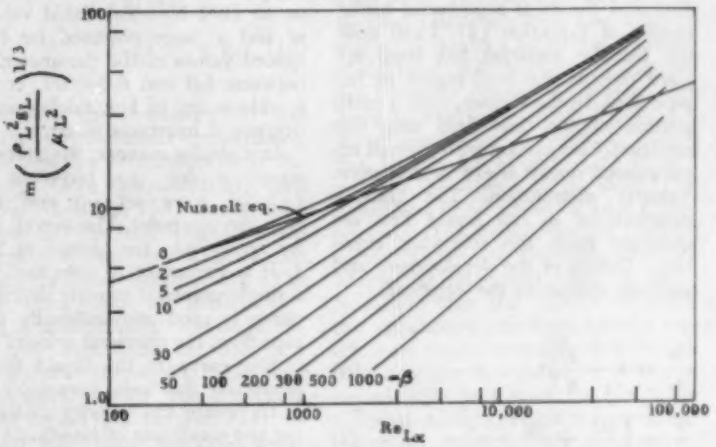

Figure 3. Film thickness.

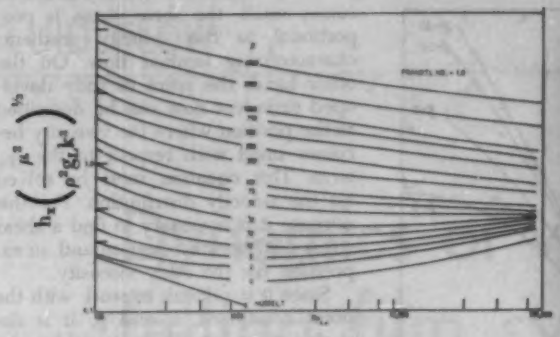

Figure 3a. Local coefficient Prandtl No. 1.0.

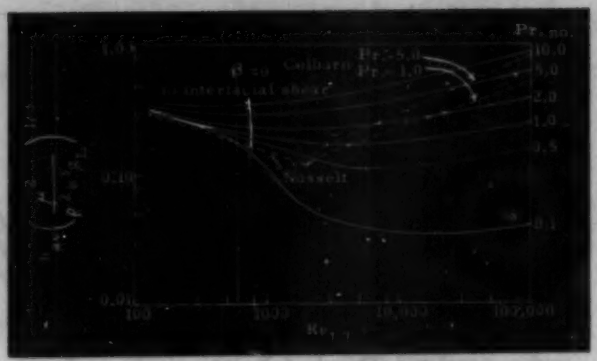

Figure 4. Average coefficient, no interfacial shear.

The key to the solution of these equations, is a suitable expression for the turbulent transport terms. Eq. (4) and (5) show the forms used.

For $y^+ \leq 20$, Deissler's equation,

$$\epsilon = \epsilon_H = n^2 u y \left(1 - e^{-\frac{n^2 u y}{\mu_L/\rho_L}}\right) \quad (4)$$

For $y^+ > 20$, von Karman's equation

$$\epsilon = \epsilon_H = \chi \left(\frac{du}{dy}\right)^3 \Big/ \left(\frac{d^2u}{dy^2}\right)^2 \quad (5)$$

In the Deissler equation (*10*), n is a numerical constant. Similarly, χ, in the von Karman equation is a universal constant. In the work reported here for films the same numerical values of n and χ were used as have been suggested for flow in full tubes.

A study of heat transfer in thin films represents a very severe test of the equations proposed by Deissler for eddy viscosity and thermal conductivity in the wall region. It will be shown below that under many conditions of film flow, the dimensionless film thickness does not exceed 20. Thus the Deissler equation applies over the entire flow field. Agreement between data and theory is a powerful confirmation of Equation (4). Until now, the Deissler equation has been applied only to the wall region in full pipe flow. In these cases, only a small portion of the flow field uses this equation. Comparison with over-all experimental results is not as definitive.

Velocity distribution. The velocity distributions in the liquid film are obtained from the following equations. Details of the development and solution appear in the Appendix

$$\frac{\tau}{\tau_0} = 1 - \frac{\sigma^3}{\eta^3} y^+ \quad (6)$$

$$\frac{\tau}{\tau_0} = \left(\frac{\mu_L}{\mu_{LO}} + \frac{\rho_L}{\rho_{LO}} \frac{\epsilon}{\mu_{LO}/\rho_{LO}}\right) \frac{du^+}{dy^+} \quad (7)$$

$$1 - \frac{\sigma^3}{\eta} y^+ = [1 + n^2 u^+ y^+ (1 - e^{-n^2 u^+ y^+})] \frac{du^+}{dy^+} \quad (8)$$

where η is the value of y^+ at $y = m$, and σ is a quantity which depends on interfacial shear and fluid properties. Equation (6), the shear stress distribution equation, was developed from a series of force balances on a fluid element. The shear stress at any point depends on the total film thickness, its weight and a term, σ, which characterizes the interfacial shear due to a moving gas phase. Equation (7) is the total shear equation previously presented, written in dimensionless velocity and distance terms. Equation (8) is the differential equation for the velocity distribution in the wall region with the shear stress Equation (6) and the Deissler Equation (4) for eddy viscosity substituted. It is valid to maximum values of $\eta = 20$. An analytical solution to this non-linear equation is not available. Solutions were, therefore, obtained numerically using the Runga-Kutta method with computations programmed and run on an IBM 650. Tabulated values of u^+ and y^+ were obtained for closely spaced values of the parameter. σ^3/η between 1.0 and 0.000001, covering a wide range of film thicknesses and degrees of interfacial shear.

In a similar manner, the differential equations for the turbulent zone ($\eta > 20$) were set up and solved with the computer. The overall results for both zones are plotted in Figure 1. It is important to note that, while a single universal velocity distribution curve is used conventionally in full pipe flow, the universal velocity distribution curve in the liquid film depends on this new parameter σ^3/η.

To obtain the velocity distribution for any conditions of interfacial shear, fluid properties, and flow rates, the parameter, σ^3/η is determined. Equations by which this is evaluated are:

$$Re_{Lx} = 4 \int_0^\eta u^+ dy^+ \quad (9)$$

$$\sigma^3 + \frac{\beta}{\eta^{2/3}} \sigma^2 - 1 = 0 \quad (10)$$

$$\beta = \frac{Fr\, g_L^{1/3}\, \rho_L^{2/3}}{2\, \mu_L^{2/3}} \quad (11)$$

Equation (9) was developed from a mass balance. Equation (10) was evolved from a series of differential force balances and the definition of friction velocity, u_*. Essentially, it relates this dimensionless term, σ, to the forces due to interfacial shear as defined by β and the forces due to gravity acting on the liquid, as characterized by η. These equations were solved in the following way. A series of values of β were selected ranging from zero (no shear) to 4000 (very high shear rates). Then a series of values of η were selected. For each pair of values of β and η, Equation (10) was solved by computer for σ, and the value of σ^3/η calculated. Equation (9) was then integrated numerically using the velocity distribution for that particular σ^3/η. The computer program for this integration and that described above to calculate the velocity distribution were coordinated so that punch card output of the first was used as input data to the second. The printout results of this calculation provided a table of values of Reynolds numbers and σ^3/η for each pair of values of dimensionless film thickness, η, and dimensionless interfacial shear, β. From this table and Figure 1 it is possible to obtain the velocity distribution for any film Reynolds number and interfacial shear. Figure 2 shows some typical velocity distributions at a Reynolds number of 132 and for β varying from 0 to 40. Note that as the value of β increases the velocity at

any value of y^+ increases. A detailed study of these curves and the shear stress show that at this low Reynolds number the shear stress is proportional to the velocity gradient over the y^+ region from zero to about 5.5, when β is zero. Over this region, then, momentum is transferred solely by a molecular mechanism. However, when $\beta = 40$, this same analysis reveals that linearity between shear and velocity gradient ceases to exist at a y^+ approximately equal to 3.5. This demonstrates the fallacy of assuming, for films, that the liquid Reynolds number alone determines whether flow is laminar or turbulent. An important secondary variable is β.

Film thickness. The Nusselt film thickness group can be readily calculated once values of σ and η have been obtained. From the definition of these terms Equation (12) can be developed.

$$m\left(\frac{\rho_L^2 g_L}{\mu_L^2}\right)^{1/3} = \sigma\eta^{2/3} \qquad (12)$$

The calculation described for velocity distribution and Reynolds number was extended to solve Equation (12). These results are shown in Figure 3. In this graph, the ordinate characterizes the liquid film thickness and the abscissa is the Reynolds number of the liquid at any point in the flow. (In a condensing system, the Reynolds number and film thickness vary down the tube). The parameter is the interfacial shear variable, β. Also plotted on this graph is the solution of the equation proposed by Nusselt for laminar flow. Note that for no interfacial shear ($\beta = 0$) and low Reynolds numbers, the theory predicts values in agreement with Nusselt. Note also that no sudden transition takes place

GREEK SYMBOLS

- β Dimensionless interface friction defined in equation (11)
- ϵ Eddy viscosity, sq.ft/hr.
- ϵ_H Eddy thermal conductivity, sq.ft./hr.
- η Value of y^+ at $y = m$
- μ_G Vapor viscosity, lb.$_M$/(ft.) (hr.)
- μ_L Liquid viscosity, lb$_M$/(ft.) (hr.)
- ρ_G Gas density, lb.$_M$/(cu.ft.)
- ρ_L Liquid density, lb.$_M$/(cu.ft.)
- σ Calculation variable defined from equation (10)
- τ Shear stress, lb.$_f$/sq.ft.
- τ_o Shear stress at the wall, lb.$_f$/sq.ft.
- χ Proportionality constant for von Karman's equation
- ϕ Two-phase pressure drop parameters

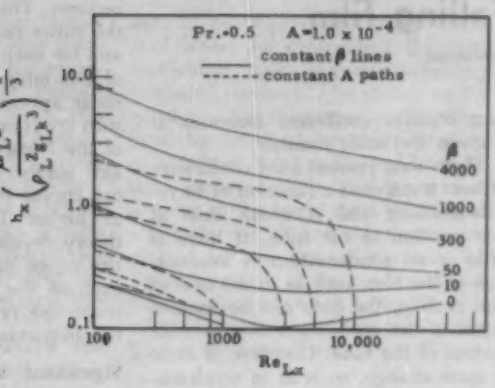

Figure 5. Plot of path lines for condensation system with interfacial shear.

at any one Reynolds number. Increased interfacial shear in the direction of motion (positive β) causes decreased film thickness. A similar series of curves could be prepared for negative values of β to represent countercurrent flow. No experimental data appear to be available which report the film thickness values with interfacial shear. Only limited reliable data are available reporting film thickness in free flow. The data obtained by Dukler and Bergelin (*12*) show excellent agreement with the line for $\beta = 0$.

Local heat transfer coefficient. The rate equation for local heat transfer at any point in the tube can be written in dimensionless terms. Following Deissler (*10*) these expressions are:

$$q/q_o = \left(\frac{1}{Pr_L} + \frac{\epsilon_H C_{PL}\rho_L}{(\mu_{LO}/\rho_{LO})C_{PLO}\rho_{LO}}\right)\frac{dt^+}{dy^+} \qquad (13)$$

$$t^+ = \frac{C_{PLO}(t_o - t)\rho_{LO}u^*}{q_o} \qquad (14)$$

$$t_+ = \frac{C_{PLO}\rho_{LO}u^*}{h_o} \quad \text{at } y^+ = \eta \qquad (15)$$

The solution to Equation (13) will give the dimensionless temperature, t^+, as a function of dimensionless distance, y^+. Once this result has been obtained, Equation (15) can be used to solve for the heat transfer coefficient for each value of the dimensionless film thickness. To solve Eq. (13) several assumptions are needed.

a. It is assumed that the eddy viscosity and eddy thermal conductivity are equal. This is a reasonably good assumption in the region near the wall (*11*). In film flow, then, it should apply over the entire film.

b. The heat flux does not change significantly through the thickness of the film and is equal to the flux at the wall. This assumption is frequently made in the application of the analogies to flow in pipes. While there may be some question about its suitability when the pipe is flowing full, it should be a very good assumption for thin films.

c. The physical properties do not change significantly in the direction of heat transfer.

With these assumptions, Equation (13) was solved on an IBM 650. Equation (4) was used for ϵ_H near the wall, and Equation (5) was substituted when $y^+ > 20$. The numerical results obtained from the computer were in the form of a table of t^+-values for various values of y^+. Using a rearrangement of Equation (15) the computer was programmed to calculate and tabulate the local heat transfer coefficient for a series of Prandtl numbers. Calculations for velocity distribution, described above, provided a tabulation of values of η corresponding to a series of Reynold numbers and β. By cross tabulating these two series of numerical results a table was obtained of the local coefficient as a function of the Reynolds number for various degrees of interfacial shear. Figure 3A shows results for one typical Prandtl No. Graphs for Pr = 0.1 to 10 appear in the Appendix. It should be noted that in all cases the heat transfer coefficient approaches the Nusselt values at very low Reynolds numbers where the interfacial shear is zero. Note also that this theory describes the variation in the heat transfer coefficients over the entire flow range from laminar flow to flow where a considerable portion of the film is in turbulent motion. There is no sudden transition. In line with experiment, as the interfacial shear increases the

Falling film

continued

heat transfer coefficient increases at a given Reynolds number.

These data present local coefficients of heat transfer as a function of Reynolds number and β which exist at one position in the tube. If there is little or no condensation or evaporation in the film, such as in the case of film cooling, the data can be used to evaluate the coefficients over a wide section of the tube. However, if there is mass change, such as in condensation, some information must be developed about the condensing path along the tube to arrive at an average coefficient. The average coefficient for *any* condensing path can be evaluated from this information.

Average coefficient for condensing systems. To evaluate the average coefficient it is necessary to integrate along the length of the tube. The applicable relation is shown as Equation (16), where Re_{LT} represents the Reynolds number of the condensate at the bottom of the tube and Re_{Ls} represents the local Reynolds number at any point along the tube. This equation is based on the assumption of constant wall-to-gas-temperature difference. However, as discussed by Seban (*5*), variable temperature differences can be accommodated.

$$h_{Av.}\left(\frac{\mu_L^2}{\rho_L^2 g_L k_L^3}\right)^{1/3} = \frac{Re_{LT}}{\int_0^{Re_{LT}} \frac{d\,Re_{Ls}}{h_s\left(\frac{\mu_L^2}{\rho_L^2 g_L k^3}\right)^{1/3}}} \quad (16)$$

For the case of *no interfacial shear* this integration is straightforward using Figure 6*, and graphical procedures. This work is repeated over the entire range of Reynolds numbers and for each Prandtl number. Results of this integration for zero interfacial shear appear in Figure 4. These results are compared with the prediction of the Nusselt equation at low Reynolds number and the Colburn empirical curves for two Prandtl numbers at higher Reynolds numbers. The theory developed here covers the entire range and generally agrees with each of the earlier theories in their respective ranges as well as covering the important intermediate region.

Significant interfacial shear. Significant interfacial shear exists in typical condenser tubes operating commercially. Furthermore, because of condensation along the tube, the amounts of liquid and vapor change along the tube, altering the pressure gradient and causing β to vary. To calculate β and its variation, a method for determining the two-phase pressure drop, and F, is required. For this purpose an empirical relationship for the two-phase pressure drop was developed using experimental data for two-phase annular, concurrent, downward flow of gas and liquid (*13*).

$$\phi_G = 3.3X^{0.22} \quad (17)$$

The parameters, ϕ_G and X are the groupings originally introduced by Martinelli (*14*).

Assuming that inlet gas to the condenser tube is a saturated vapor, and total condensation of vapor occurs before the end of the tube, the following relationship can be developed for β:

$$\beta = A\,(Re_{LT} - Re_{Ls})^{1/4}\,Re_{Ls}^{0.4} \quad (18)$$

$$A = \frac{0.250\ \mu_L^{1.172}\ \mu_G^{0.16}}{g_L^{2/3}\ D^3\ \rho_L^{0.828}\ \rho_G^{0.78}} \quad (19)$$

The path through the heat exchanger can now be plotted for any given value of A *and* Re_{LT}. Figure 5 shows several typical paths plotted for various terminal Reynolds numbers and a Prandtl number of 0.5 for the condensed phase. Once this path is obtained it is possible to calculate the average coefficient. For any one path a table is prepared of the local Reynolds number, Re_{Ls}, and the corresponding local coefficient term. The average coefficient is then obtained by integration of Equation (16). By examining the properties of a wide variety of substances at various conditions of pressure and temperature it was concluded that A would typically range from 1.0×10^{-3} to 2.0×10^{-4}. Computer solution for β was set up for a series of values of A between these limits and for terminal Reynolds numbers ranging from 100 to 50,000. The numerical results were then plot-

* *Fig. 6 of the original work is available from ADI.*

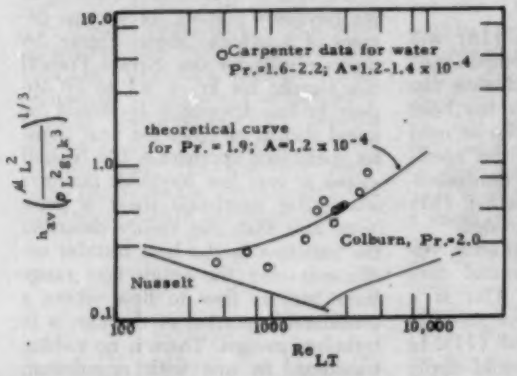

Figure 6. Comparison of theory with data—water.

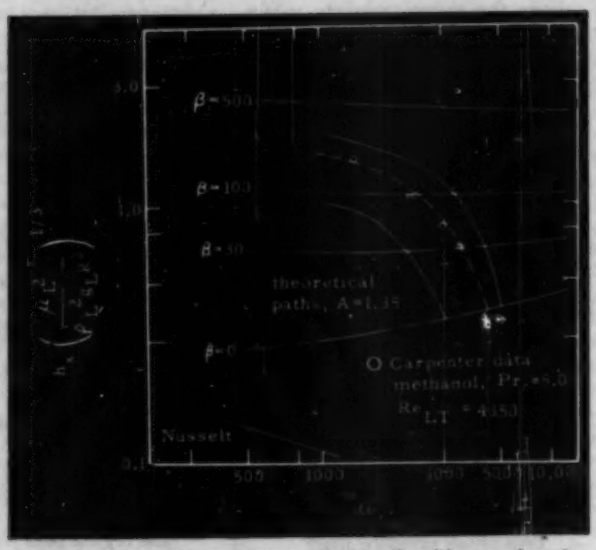

Figure 7. Comparison of theoretical path with experiment—methanol.

ted on the point coefficient graphs and these paths used to graphically integrate for the average coefficient.

Results of this series of integrations have been plotted in Figures 9 to 11* for several Prandtl numbers ranging from 0.1 to 10. These figures may be considered the design graphs for vertical downward condensation. The Appendix includes graphs for Prandtl numbers of 0.1, 0.5, 1.0, 2.0, 5.0, and 10.0 plotted on a coordinate grid. The results apply over a wide range of Reynolds numbers, fluid properties, and tube sizes. They can be expected to apply to condensation in horizontal tubes at high Reynolds numbers, when annular flow exists over most of the tube length. It is important to note that in the general case three factors must be fixed to determine the average coefficient. These are: the terminal Reynolds number, the Prandtl number of the condensed phase, and the dimensionless group, A. A comparison between Figures 9-11* reveals that a low Prandtl number system with a high A will produce a higher heat transfer coefficient than a high Prandtl number system operating under conditions of low A. Much of the very bad scatter in literature data can be explained on this basis.

Integration for cases where the vapor is not totally condensed, where some liquid enters with the gas, or where a large change in properties takes place can be treated readily by redeveloping the path equation and using the local coefficient graphs. Countercurrent flow cases may be treated after the numerical work is repeated for negative values of β.

NOTATION

- A = Dimensionless group defined in equation (19)
- C_{pL} = Specific heat of liquid, Btu/(lb) (°F)
- C_{pLo} = Specific heat of the liquid at the wall, Btu/(lb) (°F)
- D = Tube diameter, ft.
- F = Frictional pressure gradient divided by liquid density, dimensionless
- g_c = Newton's conversion factor, $(lb_M)\ (ft.lb_f)\ (sq.hr.)$
- g_L = Acceleration of gravity, Ft/sq.hr.
- h_{AV} = Average coefficient over the tube length, Btu/(hr.) (sq.ft.) (°F)
- h_x = Local coefficient, Btu/(hr.) (sq.ft.) (°F)
- k_L = Liquid thermal conductivity, Btu/ (sq.ft.) (hr.) (°F/ft.)
- m = Liquid film thickness, ft.
- n = Numerical constant in Deissler equation
- Pr = Prandtl number
- q = Heat flux at any position, y. Btu/ (hr.) (sq.ft.)
- q_o = Heat flux at the wall, Btu/ (hr.) (sq.ft.)
- r = Tube radius, ft.
- Re_{Lx} = Local film Reynolds number for liquid, dimensionless
- Re_{LT} = Terminal film Reynolds number for liquid at the bottom of the tube, dimensionless
- t = Temperature, °F
- t_o = Temperature at the wall, °F
- t^+ = Dimensionless temperature defined in equation (14)
- u = Local velocity at position y, ft/hr.
- u^+ = Dimensionless velocity, u/u_*
- u_* = Friction velocity, ft./hr.
- y = Distance from the wall, ft.
- y^+ = Dimensionless distance, $u_* \rho_L y / \mu_L$

Comparison of theory with experiment

Direct measurement of the condensate coefficient has been difficult due to problems in the determination of the surface temperature. The alternate method of evaluating the condensate resistance and coefficient from overall coefficient measurements is usually inaccurate because of the low resistance of the condensation side compared to the other resistances in series. The most reliable data recently published seems to be that by Carpenter (*15*). Carpenter obtained both average and local coefficients for a series of substances. These data permit a test of the path equations proposed here as well as the theoretical results for the average coefficients of the graphs. Figure 6 shows the average coefficient data for water as determined by Carpenter at various terminal Reynolds numbers. These data covered a Prandtl number range from 1.6 to 2.2 with values of A ranging from 1.2 to 1.4. For comparison, the theoretical prediction for a Prandtl number of 1.9 and an A of 1.2 is plotted. The agreement here is satisfactory. Closer agreement is obtained if a series of theoretical curves is drawn covering the range of Prandtl numbers and A represented by the data.

A more severe test of this theory is the evaluation of the equations which predict the path through the condenser tube when the amount of condensate varies. Carpenter presented limited data of this type. Shown in Figure 7 are the experimental results of one Carpenter run for methanol where he determined the local coefficients and the corresponding Reynolds numbers. Also shown on the graph are the theoretical paths calculated for terminal Reynolds numbers of 3000 and 5000 and interpolated for the conditions of the run. Agreement is seen to be very good. Note that although the theoretical curves are plotted for one Prandtl number, the Prandtl number of the condensate actually varies down the tube. There is need of more data of this sort to test further theoretical work.

* *Figs. 9-11 of the original work are available from ADI.*

Conclusions

Graphical relationships have been presented which allow the determination of the velocity distribution, the liquid film thickness, the local heat transfer coefficient and the average coefficient over an entire condenser tube. These determinations can be made from the external flow rates, the properties of the fluids, and the tube dimensions. Final theoretical results, when compared with experimental data give good agreement. In addition to justifying the several assumptions made in the course of the development, this agreement appears to have confirmed the usefulness of the equation of Deissler for the eddy viscosity near a solid boundary.

ACKNOWLEDGMENT

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An engineer contractor looks at the pilot plant

There is a growing appreciation of the fact that the designer of commercial plants should participate in the pilot-plant phase of new process development.

The ultimate purpose of a pilot plant is the purchase of time at the best possible price, and the determination by the most effective means of the necessary data required for the design of a profit-making commercial plant. Pilot plants are generally expensive in dollars and in time. The data needed for full-scale design must be carefully analyzed to determine alternative means to arrive at answers that can be used with confidence by the designers of the proposed full-scale plant. The pilot program should be carefully edited, and programmed to ensure that missing data will be determined and that the parameters involved in the pilot scale are such that extrapolation to full scale can be made with reasonable confidence.

The engineer-contractor is oriented toward eventual design and construction of full-scale plants. He is able to introduce into pilot-plant programming a number of important elements which otherwise might not receive early consideration. This premise is based on the assumption that the engineer-contractor will assume the responsibilities for the design and installation of the pilot plant. The word "responsibility" may be open to challenge in that the engineer-contractor is engaged to supplement and to work cooperatively with the client on a process or processes which the client has either developed in his laboratory, or has obtained from others, or from literature research.

The engineer-contractor, therefore, brings to the team a point of view directed toward the ultimate success of a full-scale plant. Being familiar with the design and construction of large industrial processes, he is alert to the type and kind of data which will be needed from pilot-plant operation. This point of view is not often coupled with the needed point of view at the laboratory level. It is not that the engineer-contractor's personnel know more than the R&D staff, but rather that they know less about the processes under consideration. Familiarizing the engineer-contractor with the new program, its relationship to the clients' current activities, and its place in the near future of the industry helps to crystallize the factors essential to success. The engineer-contractor can then assist in focusing the program toward securing information actually required in the ultimate scale-up.

Type of data required

For the commercial development of a new process, the design engineer usually needs fundamental data rather than data of an engineering nature. Complete thermodynamic and physical property data are frequently lacking at the inception of a project. These can often be obtained by bench-scale tests without resort to a costly pilot plant. When yield data are required, it is often necessary, or at least desirable, to obtain this information from a pilot plant, since the bench-scale apparatus is not always a reliable indication of the yields that may result under commercial conditions. It is also true that a pilot plant cannot give full-scale answers straight across the board, since any prototype less than full-scale involving chemical and physical processes, cannot preserve geometric similarity and maintain chemical and physical similarity. It is advisable to determine which type of similarity will give answers that can be extrapolated to full-scale with confidence. Sometimes, the combination of bench-scale data and pilot-plant data will indicate which type of similarity can best be preserved in the scale-up. In any event, the differences in behavior of the pilot plant and bench scale will give as much important information as the similarities.

There is much fundamental data that can be scaled up to commercial design without the expense and travail of piloting. Fundamental data on fluid flow, distillation, heat transfer, and many other chemical engineering

unit processes are generally amenable to scale-up without the pilot step. Of course, processes involving a new chemical engineering concept must be piloted. Often, processes involving solids handling, either as aerosols or as a fluid slurry, and mundane problems such as solids transport behave in such recalcitrant ways that some sort of pilot program is warranted to offset the possibility of a costly full-scale problem.

Minimizing the pilot program

Process piloting can often be minimized by first obtaining limited data from a sample plant incorporating only the equipment necessary to demonstrate the new process concept. With these data the design engineer can attempt a "first pass" through the process design. This may reveal holes in the available data which can then be plugged by further piloting limited to a specific goal. In this manner, the pilot program can be reduced to one with a few definite purposes, and the time from concept to commercial production may be significantly reduced. Such a procedure may be particularly desirable where competitive situations dictate a minimum time from concept to production. It is quite likely that the engineer can suggest simplifications of the pilot-plant program by virtue of his familiarity with commercial design and methods known to him, or available in the literature. It is often possible to provide the engineer with much of the required information in the form of basic data. The pilot plant may be simplified, and the time required to obtain the necessary data reduced by addressing the pilot program to those specific data which cannot be predicted with confidence by any other available means.

Dangers in pilot data

Even in the rare cases where smooth results and essentially complete pilot plant data have been developed, the design engineer must be alert for scale-up problems. Competent pilot work may be seriously misleading to the design engineer, unless he critically analyzes the pilot equipment, materials of construction, program, procedures, method of obtaining data and analyses, and the duration of runs. He must anticipate what was *not* observed, as well as what was actually determined, because of characteristics common to many pilot plant operations, such as:

1. Process steps which will use feed from commercial operations may be piloted with synthetic feed stocks made up in the laboratory. Trace impurities present in the commercial feed might affect the process results materially.
2. Commercial operations involving recycle streams are often difficult and expensive to pilot. As a simplification of the pilot plant, the recycle may be simulated, or the stream synthesized. In this case, false conclusions may result from failure to assume the proper equilibrium recycle composition in the pilot plant.
3. The relatively short duration of most pilot programs may prevent the recognition of slow accumulations of trace catalyst poisons.
4. In small-scale pilot streams, the technique of sampling must be considered with regard to its effect on reaction equilibrium.
5. Pilot plants are often assembled partially from equipment on hand. The construction materials may differ considerably from those which would be used in a large-scale plant. Laboratory-type equipment, glass coils, glass-lined reactors, and plastic tubing may be used. In this way, the catalytic effects of nickel, chromium, and other alloy materials may be overlooked.
6. Various parts of the pilot plant may be considerably oversized because of equipment availability. In such a case, fouling of lines and equipment may go unnoticed through a pilot program. If these possibilities are not recognized, the scale-up may not provide proper provisions for sparing, cleanout, and allowance for costly down time.
7. Often two classes of data result from pilot plant work, neither of which manifests itself in laboratory work. One type is peculiar only to the pilot plant, and would not exist in the full-scale plant. These are associated with the anomalies of scale-up similarity, solids handling, the effect of instrumentation, and lack of availability of "scale-down" equipment of mechanical similarity to that which would be used in full-scale operation. Problems of this nature can cause delays and interruptions which would not occur in full scale, and make it difficult to obtain accurate operating data where smooth continuous processes, involving established equilibria, are indicated. The other class of data are the unforeseen problems which were not specifically sought, and yet are not peculiar to the pilot-plant scale. These may provide early warning of significance to the design of the full-scale plant.

Engineer-contractor contributions

The engineer-contractor's staff are familiar with "as built" costs, and are in a position to make realistic economic comparisons of alternate process routes and equipment design. They are trained to be highly cost-conscious. They tend to seek out simple, rather than complicated, solutions to the problems. They are conscious of the cost of time between the research stage and ultimate operation. They are used to working under tight schedules. The staff is familiar with a large variety of processes and process equipment, some of which are likely to be applicable to the proposed process. Their knowledge of the relationship of the process to the necessary service and utility facilities may have important consequences on the comparative economics of alternate processes. This is especially true where such factors as air pollution, stream pollution, and noise abatement, all enter into initial and operating costs of modern plants. These are factors added to the normal factors of plant location with respect to raw materials, markets, power and fuel, water, safety and fire protection, and by-product and waste disposal Competent research people are not generally so burdened with these auxiliary and consequential requirements of commercial designs.

A joint endeavor

Once the process philosophy has been established, the programming of the pilot plant and its detailed design can benefit from a joint development. By coming in from the "outside," so to speak, and being required to analyze the available data from bench work, from fundamental literature research, and from the ideas given him by the client's staff, the engineer-contractor must soon crystallize the un-

continued

Engineering contractor

continued

known areas that are essential to the final process. He can assist the R & D people in determining the type of scale-up which would have meaning and could be used with confidence in the ultimate design. Together, they can contribute to the efficient chemical engineering of the equipment and its instrumentation.

The contractor's design engineers can help to achieve compact, accessible equipment layout, assist in the choice of materials and mechanical equipment, and in the selection of appropriate suppliers, as well as supervise the necessary drawings. His project engineer will be concerned with the over-all coordination of the research staff with the engineers, and, in addition, will have the responsibility of scheduling and maintaining the schedule. Because of the engineer-contractor's long-time position as an important customer, his purchasing and expediting staff can often obtain the best possible price and delivery.

Conclusion

The engineer-contractor, participating in the early programming stage of pilot plant work, brings to the client a different background, a somewhat different point of view, and perhaps even a certain amount of naiveté with respect to the client's business and proposed expansion. As an outsider, his objectivity may be an essential catalyst in the gelation of a sound pilot program.

To obtain the necessary information, it is likely that he will clarify many concepts merely because of his lack of intimate knowledge of the problems peculiar to the client's business. Retained in the position of engineer-contractor at the pilot stage, he is given ready access to information and data which are needed for the program. He is able to feed back to the laboratory and pilot plant staff requests for specific data which will round out design information most pertinent to commercial design. He can cross the normal corporate lines of communication to obtain the different points of view which generally exist among research, engineering, operations, and sales.

A serendipic benefit to the client is that, while they are pilot-planting a process, they are coincidentally pilot-planting an engineer-contractor. This may have an important bearing on the success of the full-scale plant.

Scale-up of mixer-settlers

Although mixer-settlers are one of the oldest types of contactors used for liquid-liquid extraction, there are few published methods of scale-up. More rarely has there been any attempt to verify the methods from the operational data of full-scale plants.

Results of previous studies of agitated vessels have suggested several methods of scale-up of mixers. Miller and Mann (*7*) in their study of degree of mixing in unbaffled tanks suggested scale-up by use of constant power input per unit mixer volume; Flynn and Treybal (*2*) found that stage efficiency was independent of mixer size at constant energy input per unit volume liquid processed; and Karr and Scheibel (*4*) demonstrated scale-up as a function of powers of agitator speed and diameter.

For settlers, the suggested method of scale-up often has been based on residence time (*9*). Many patents have been granted for particular settler configurations, but references to experimental demonstration of scale-up generally are not available.

Investigation of design and scale-up of mixer-settlers was a part of the development of the Dapex (*1*) solvent extraction process for recovery of uranium from sulfuric acid leaching of ores. The process uses di(2-ethylhexyl)phosphoric acid dissolved in kerosene modified with TBP as the solvent, which extracts uranium by cation exchange of uranyl and hydrogen ions. The uranium is stripped from the solvent by an aqueous solution of Na_2CO_3 from which uranium is recovered by standard precipitation methods.

The basis for design of equipment for the process was obtained by unit operation study of the variables affecting rate of extraction in the mixer and phase separation in the settler. Scale-up relations were developed from data obtained in three sizes of geometrically similar units. This information, together with chemical flow sheet demonstration in laboratory-size multistage equipment, was used as a basis for design of full-scale plants without operation of a pilot plant.

Mixer

The mixer was a baffled tank agitated by a flat-blade turbine centered in the liquid. The liquid depth was

Flexibility is essential in pilot plant operation. Photo courtesy Deco Trefoil.

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Table 1. Composition and physical properties.

Solvent	SYSTEM A	SYSTEM B
Di(2-ethylhexyl) phosphoric acid, molarity	0.16	0.10
Tributylphosphate, g./l.	35	30
Diluent	kerosene	kerosene
Density, g./cc.	0.83	0.82
Viscosity, centistoke	2.4	2.3
Aqueous Feed, g./l.		
U	5.2	1.2
Fe^{+3}	0.52	0.33
Al	2.6	2.8
V (total)	4.8	0.94
V^{+4}	1.4	0.94
SO_4	89	51
pH	0.3	1.1
Density, gm./cc.	1.08	1.05
Viscosity, centistoke	1.14	1.06
Interfacial Tension, dynes/cm.	18.3	19.0
Phase Ratio *A/O*	1/1	4/1

equal to the tank diameter. The dimensions of the three sizes tested are shown in Figure 1. The power input to the mixer was calculated using correlations of turbine size, speed, and liquid properties as reported by Rushton (*8*) and Laity (*5*):

$$P = (K/g)\rho N^3 D^5 \qquad (1)$$

The mixers were operated both batchwise and in continuous flow using two chemical systems (Table 1) encompassing a range of compositions, solvent strengths, and phase ratios typical of actual uranium mill solutions. The equilibrium distribution of uranium for both systems is shown in Table 2.

In the Dapex process, the rate of uranium extraction is first order with respect to uranium concentration in the aqueous phase. The rate constant for batch mixing, derived in a manner similar to that reported by Hixson and Smith (*3*) is:

$$ka = -\ln (1-E)\ (1/t)\ (R/V) \qquad (2)$$

The corresponding equation for continuous flow, derived by the method of MacMullin and Weber (*6*) is:

$$ka = (E/1-E)\ (1/t)\ (R/V) \qquad (3)$$

Thus the rate of extraction is expressed in terms of stage efficiency, E; contact time, t; and fraction of aqueous phase in the mixer, R/V. The stage efficiency is the fractional approach to equilibrium based on the uranium concentration in the aqueous phase. Because of the shape of the equilibrium and operating curves, there is very little difference between E used here and the Murphree E based on the aqueous phase.

The basis for design was obtained by measuring the effect of power input, turbine to tank diameter ratio, and type of dispersion on the rate constant over a range of contact times for both chemical systems. Scale-up relations were determined batchwise in 6-, 12- and 20-in. diam. mixers and with continuous flow in 6- and 12-in. mixers. All tests were made at 25°C.

Table 2. Equilibrium distribution of uranium.

Conc. g. U/liter			
System A		System B	
Aqueous	Solvent	Aqueous	Solvent
5.1	9.8	0.96	6.2
4.3	9.2	0.57	5.6
3.3	9.0	0.30	5.0
2.4	8.6	0.20	4.5
1.3	7.9	0.11	4.0
0.44	6.2	0.034	3.3
0.17	4.9	0.013	2.2
0.12	4.0	0.002	1.1
0.045	2.6		
0.019	1.7		
0.010	1.1		
0.006	0.65		

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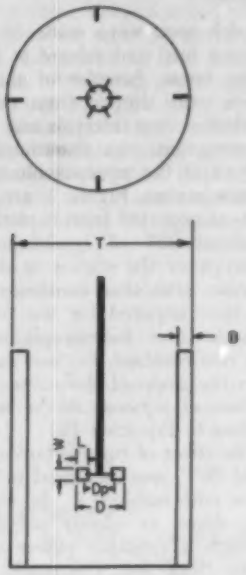

T	D	B	V
inches			gallons
6	2	0.6	0.74
12	4	1.2	5.9
20	6	2.0	27.0

DIMENSION RATIOS OF TURBINE
D : Dp : L : W = 24 : 16 : 6 : 5

Figure 1. Baffled tank mixers.

Figure 2. Typical rate of extraction in 12-in. batch mixer.

continued

Batch tests were made by mixing aqueous feed and solvent at constant power input. Samples of the mixed phases were dipped from the mixer at selected time intervals and the rate of extraction was determined from analysis of the aqueous phase. Typical rate curves, Figure 2, are straight lines, as expected from Equation (2), to about 95% of equilibrium. The intercept of the curves is displaced because extraction continues during the time required for the phases to separate after the sample is taken. The rate constant, ka, was calculated from the slope of the curve and the fraction of aqueous in the mixer according to Equation (2).

The effect of turbine-tank diameter ratio, D/T, was measured in a 12-in. mixer with turbines 2-, 3-, 4-, 6- and 8-in. diam. at speeds calculated to produce a constant power input of 20 hp./1000 gal. The results in Figure 3 show that the rate constant increases nearly linearly with decreasing D/T. The most efficient use of power was obtained using a small turbine rotating at a high speed, which is consistent with Rushton's predictions (8) for mass transfer operations.

Correlation of batch-rate constants with power input for both chemical systems in 6-, 12- and 20-in. diam. mixers at D/T ratio of ⅓ is shown in Figure 4. The slope of the curve is about ⅓, indicating that the rate of extraction is proportional to the cube root of power input over the entire range of 2.5 to 220 hp./1000 gal. The close agreement of data for each chemical system demonstrates that the rate of extraction is virtually independent of uranium concentration over the range of 1 to 5 g/l. On the average, ka was greater for a phase ratio (A/O) of 1/1, than for 4/1. Extrapolation of interfacial area data by Vermeulen (10) showed that the specific interfacial area at 1/1 is about 1.4 times that at 4/1. Multiplying the values of the rate constants by this factor would reverse the relative positions of the curves for different phase rations in Figure 4 with about the same spread shown.

The data in Figure 4 also show that the rate of extraction is virtually independent of mixer diameter, at constant power input per unit volume, over the entire range of power input studied. This provides a simple method of scale-up based on constant pow-

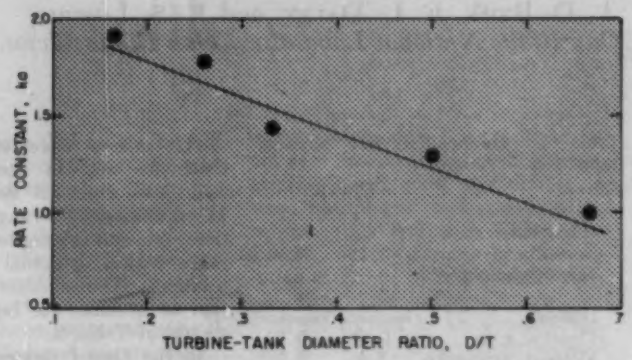

Figure 3. Effect of D/T on rate of extraction in batch mixer.

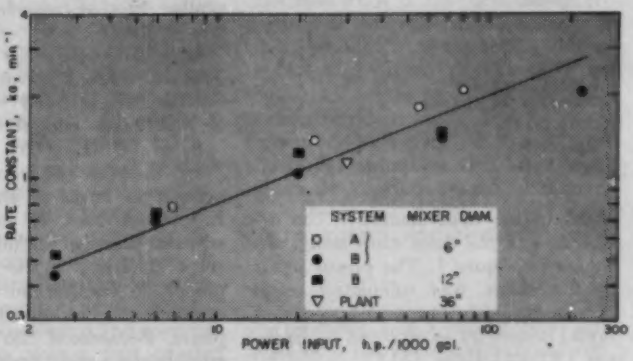

Figure 4. Batch extraction in baffled tank mixers.

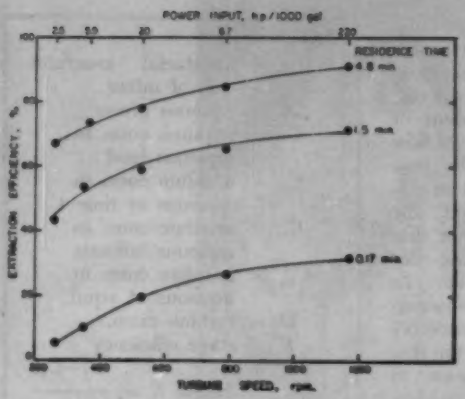

Figure 5. Stage efficiency of 6-in. mixer with continuous flow.

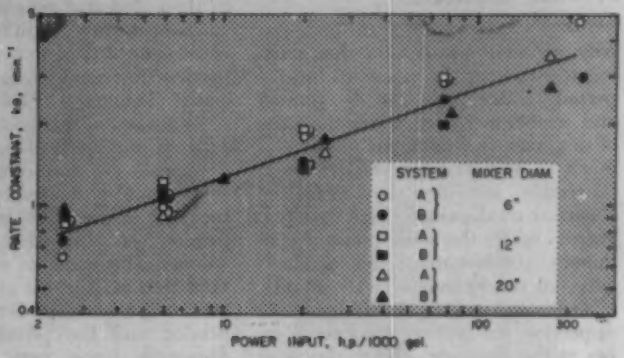

Figure 6. Rate of extraction in continuous flow mixers.

er input per unit volume which was previously reported by Miller and Mann (7). Other correlations based on Weber or Reynolds numbers did not suggest any better method of scale-up.

Continuous flow

Continuous-flow tests were made by operating the mixer with constant power input and constant flow of aqueous feed and solvent, and then sampling after steady state was established. In continuous flow, it is difficult to obtain samples representative of the extraction that occurs in the mixer only, because extraction continues during the time required for phase separation. The best correlation of rate constant with power input was obtained by sampling the dispersed phase through a preferentially wetted porous filter directly from the mixer. Samples of solvent were obtained through fritted teflon and aqueous phase through fritted glass.

The stage efficiency calculated from frit samples increased with increasing power input and residence time as shown in Figure 5. The rate constant, ka, calculated from the stage efficiency at constant power input is nearly independent of residence time over the range of 0.17 to 4.8 min., as predicted by Equation (3). The average rate constant at $D/T = \frac{1}{3}$ plotted against power input, Figure 6, confirms the batch correlation with respect to both power input and scale-up, although the values of ka are about $\frac{1}{3}$ of those obtained with batch mixing.

Because extraction continues during phase separation, the stage efficiency of a mixer-settler unit is greater than that measured in the mixer only, depending on the residence time of dispersion in the settler. After the design of the settler is selected, the total contact time can be used in Equation (3) to give the approximate stage efficiency of the mixer-settler unit.

Confirmation of scale-up has been obtained from analysis of the Dapex solvent extraction circuit at a uranium ore processing mill. The plant mixers are a direct scale-up of the baffled tank mixers shown in Figure 1. Each mixer is 36 in. diam. with a power input of 30 hp./1000 gal. The flow rates of aqueous and solvent were 40 and 70 gal./min., respectively, resulting in a residence time of dispersion of 1.2 min. in each mixer and 1.4 min. in each settler. The stage efficiency in mixer only, and in mixer-settler for three stages, is shown in Table 3. The rate constant based on the average stage efficiency of the mixer, plotted in Figure 6, fits on the curve drawn for 6- and 12-in. mixers, confirming the scale-up relations developed in the models.

Settler

The variables affecting phase separation were determined by operating a single mixer-settler unit in a closed circuit Figure 7. Phase separation in gravity settlers is characterized by a uniform dispersion band at the interface, the thickness of which serves as an index to flow capacity for various systems. The interface was maintained at the midpoint with an adjustable gravity leg on the aqueous discharge stream. The dispersed phases flowed from the mixer by gravity and entered the settler at the interface level near the settler wall opposite the discharge nozzles.

The flow capacity of settlers was determined for both oil-in-water and water-in-oil dispersions. Either type of dispersion can be made and maintained by starting the agitator with

continued

Table 3. Stage efficiency of plant mixer-settlers.

Stage No.	Uranium Concentration in Aqueous, g./l. Feed	Equil.	Mixer Effluent	Settler Effluent	Stage Efficiency, % Mixer	Mixer-Settler
1	5.2	1.35	2.10	1.62	80.5	93.0
2	1.62	0.073	0.40	0.20	78.7	91.6
3	0.20	0.010	0.053	0.023	77.4	93.2

Table 4. Nominal flow capacity of settlers.

Type of Dispersion	Phase Ratio, A/O	Aqueous Flow Rate, gal./min./sq. ft. 6-in.	22-in.	48-in.
Water-in-oil	1/2	1.1	1.2	1.1
	1/1	1.1	1.5	1.1
Oil-in-water	1/1	1.4	1.4	1.4
	4/1	4.4	4.6	4.1

Table 5. Dispersion band in plant settlers.

Temp., °C	Flow Rate, gal./min. Aqueous	Solvent	Settler Diameter, ft.	Dispersion Thickness, in. Actual	Predicted*
32	40	70	7	5.5	3.5
40	230	230	16	5.5	4.5

* Corrected for temperature difference. (ORNL 2399).

Mixer-settlers

continued

only one phase present and then starting the flow of the phase to be dispersed. Either type can be formed and maintained even when the ratio of dispersed to continuous phase is as much as 3/1. The type of dispersion is readily identified by measuring electrical conductance: high conductance indicates the water phase is continuous (oil-in-water); low conductance, oil is continuous (water-in-oil).

At steady state, a distinct band of dispersion (of uniform thickness) exists at the interface. The thickness of the band increases exponentially with increasing flow until the settler is flooded. By measuring the dispersion thickness as a function of flow rates, it is possible to define the relative effects of mixing power, flow patterns, and phase ratio on throughput capacity of the settler for either oil-in-water or water-in-oil dispersions.

Variation of power input to the mixer or flow distributors in the settlers have virtually no effect on the flow capacity of the settler.

The results of tests in 6-, 22-, and 48-in. diam. settlers at 25°C, are shown in Figure 8, where dispersion thickness is plotted against aqueous flow rate per unit cross-sectional area, for both oil-in-water and water-in-oil dispersions at phase ratios (A/O) of 1/2, 1/1, and 4/1. The result is a family of nearly parallel curves showing that the dispersion thickness increases about sixfold when the flow rate is doubled.

Each curve represents data obtained in three different diameter settlers at constant mixing conditions. The close agreement of data shows that the dispersion thickness is independent of settler diameter over the range of flow rates tested. Consequently, the flow capacity is directly dependent on settler area. On the other hand, the steep slope of the curves shows that the flow capacity is much less dependent on dispersion thickness or volume. This confirms visual observations that most of the coalescence occurs at the interface between the dispersion and the phase common to dispersed drops; very little coalescense of drops occurs within the dispersion band. Coalescence was also observed on the walls of the settler when the dispersed phase wet the walls, *i.e.*, water-in-oil-type dispersion in a glass vessel, or an oil-in-water dispersion in a plastic settler. The wall effect is significant in small settlers where the ratio of wall area to cross-sectional area is large. Therefore, for valid scale-up from small settlers, a glass vessel was used for oil-in-water dispersion and a plastic vessel for the water-in-oil type.

From the curves in Figure 8, the flow capacity of the settler can be defined in terms of flow rate per unit cross-sectional area at constant dispersion thickness. The depth of the settler is primarily determined by the sensitivity of interface control system. For simple gravity leg control, a total liquid depth of 2 ft. is usually sufficient for expected variations of density of the phases. The nominal flow capacity for design purposes has been arbitrarily selected as one half of the flow rate causing flooding of the settler, which for a 2-ft. deep settler would be at a flow rate giving a 3-in.

NOTATION

- a = interfacial area/unit vol. of mixer
- A = aqueous phase
- C_f = uranium conc. in aqueous feed
- C_t = uranium conc. in aqueous at time t
- C_r = uranium conc. in aqueous raffinate
- C_{eq} = uranium conc. in aqueous at equil.
- D = turbine diam.
- E = stage efficiency:

  batch; $E = \dfrac{C_f - C_t}{C_f - C_{eq}}$

  continuous; $E = \dfrac{C_f - C_r}{C_f - C_{eq}}$
- g = gravity conversion factor
- K = turbine constant
- k = specific rate constant
- N = turbine speed
- O = solvent phase
- P = power input to mixer
- R = vol. of aqueous in mixer
- T = mixer diam.
- t = contact time in mixer
- V = vol. of mixer
- ρ = mean dispersion density

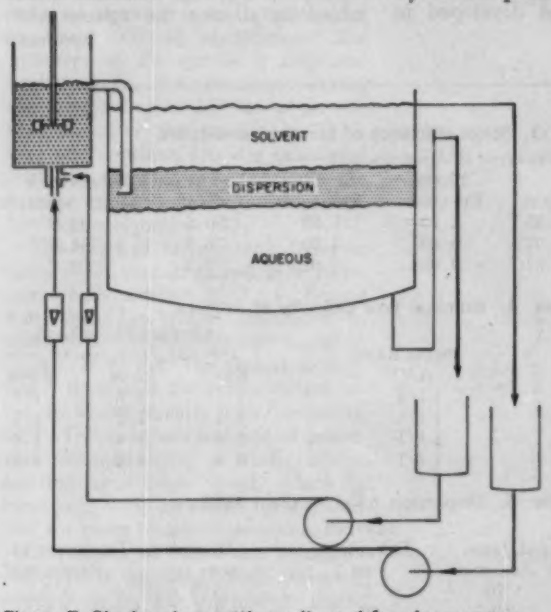

Figure 7. Single mixer settler unit used for phase separation tests.

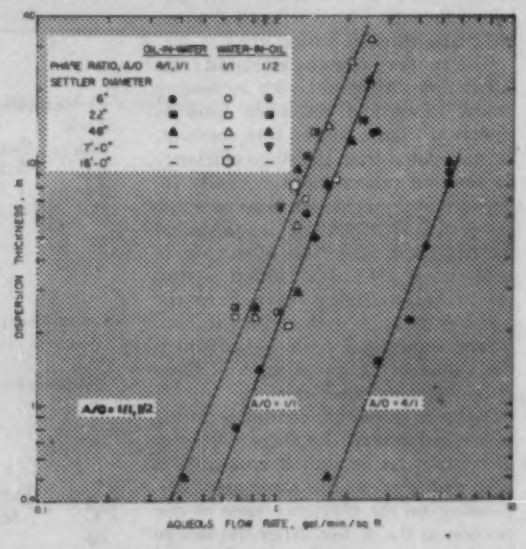

Figure 8. Flow capacity of settlers.

The solvent extraction circuit is a complete circuit incorporating extraction mixers capable of the desired recirculation of the organic phase, settlers for separating the organic and aqueous, and stripping mixers and settlers. Photo courtesy of Deco Trefoil.

dispersion band. Equally valid bases for flow capacity can be selected at any other dispersion thickness because the curves are parallel.

Comparison of the nominal aqueous flow capacity of 6-, 22- and 48-in. diam. settlers (Table 4) demonstrates scale-up based on flow rate per unit cross-sectional area at constant band thickness for each system. The aqueous flow capacity increases with increasing ratio of aqueous to solvent in the dispersion and, in general, is greater for oil-in-water than for water-in-oil dispersions.

Good agreement of plant data with that obtained in scale models, as shown in Table 5 and Figure 8, demonstrate valid scale-up of settlers based on flow rate per unit cross-sectional area.

Entrainment

Entrainment of solvent in the aqueous phase was dependent on both the type of dispersion and phase ratio. With water-in-oil dispersions the entrainment was consistently less than 0.02% and with oil-in-water dispersions it ranged from 0.02% at a phase ratio (A/O) of 1/1 to 0.3% at 4/1. This is consistent with the generalization that the continuous phase usually contains a haze of the dispersed phase after primary phase separation.

Emulsions

Phase-separation tests on samples of different plant-leach solutions revealed that the presence of colloidal silica or clay stabilized emulsions of the oil-in-water type. Emulsion formation could be avoided almost completely with these solutions by controlling the mixing to form a water-in-oil-type dispersion.

Conclusions

1. The rate of uranium extraction in the Dapex process is proportional to the cube root of power input for both batch and continuous flow if the extraction in the mixer only is measured.

2. Mixers can be scaled-up by geometric similitude at constant power input per unit mixer volume, demonstrated in 6-, 12-, 20- and 36-in. diam. mixers, representing a volumetric scale-up ratio of 200 to 1.

3. The flow capacity of settlers is characterized by a band of dispersion at the interface, the thickness of which is a measure of the approach to flooding.

4. Settlers can be scaled-up based on flow rate per unit cross-sectional area, demonstrated in settlers 6 in. to 16 ft. diam., representing an area scale-up ratio of 1000 to 1.

5. Control of mixing to form water-in-oil dispersions is recommended to minimize solvent entrainment and emulsions with solutions containing colloidal material which stabilize oil-in-water emulsions.

Acknowledgment

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Evolutionary operation

A program for optimizing plant operation through the application of statistics to scale-up problems.

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When a process is transferred from the laboratory into full-scale equipment, the relationship between the variables remains approximately the same. For example, if it is found in the laboratory that as the temperature is increased the yield rises to a maximum and then falls, approximately the same relationship will be maintained in plant equipment. However, if 78°C was optimum as determined by a thermometer inserted in a glass beaker, it does not necessarily follow that 78°C is the optimum as measured by a thermocouple in a large steel pot. Anyone associated with a production process is aware of the difficulty in transferring conditions established in the laboratory, or pilot plant, into full-scale equipment. This situation is even clearer when mechanical variables are considered. No imagination is required to see the difficulty in translating the revolutions per minute of a glass stirrer to the agitator of a tank. As a result, the contour system describing the relationship between the variables will usually be displaced and even distorted because of scale-up effects, Figure 1.

When serious difficulties are encountered in operating the plant, or when there is reason to expect that major improvements should be rapidly obtained, it may be wise to turn the plant over to experimental operation for a short time. By using a carefully chosen statistical pattern, it is possible to test many factors in a limited period of time. Of course, several major difficulties are encountered with this approach. By its very nature, the design will upset production, and usually special facilities and personnel will be needed to ensure that the complex array of experiments is properly carried through. In addition, it must be expected that some batches, as designated by the design, will produce very low yields, high levels of impurity, etc.

The use of a designed experiment can certainly be justified when a plant is faced with a very sick process, and the necessity of a reasonably fast cure—a crash program. However, the vast majority of processes are just slightly ill, and when faced with the prospect of an experiment disrupting production, management frequently decides that the cure is worse than the disease.

For example, it is common to find a process producing yields 80% of theoretical, while optimum laboratory conditions will produce 88%. Certainly management would like to approach, if not surpass, the 88%, but if the process is profitable at 80%, and sales are heavy, the motivation to approve a crash program is weak indeed. Evolutionary Operation is designed for this type of application.

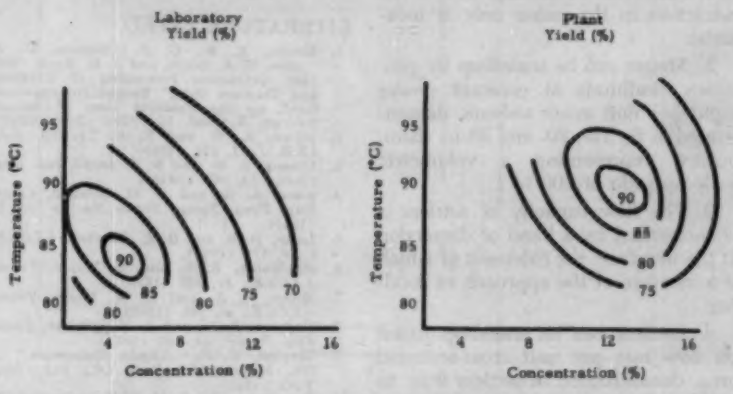


Figure 1. The contour system describing the relationship between the variables will be displaced or even distorted because of scale-up effects.

Natural evolution vs. evolutionary operation

There are two basic elements in the process of natural evolution:

1. Variation
2. Selection

Since no two things are produced exactly alike in nature, variation certainly exists. By some principle, such as survival of the fittest, the undesirable members of the class under consideration are gradually reduced in favor of the desirable members. Because the variation and selection are continuing processes, the group gradually moves toward optimum characteristics.

Evolutionary Operation emulates this natural process by artificially introducing variation and selection to the manufacturing process. They are introduced in such a way that there is little danger of producing unsatisfactory material, production is not disrupted, and the normal plant personnel can continue to operate the plant on a routine basis. Evolutionary Operation is a permanent method of plant operation, not something applied on a short-term basis. It works by gradually pushing the process toward its optimum operating condi-

tions. Since the method is permanent, only techniques which can be readily understood by the manufacturing personnel are used.

General description

Slight variation, aside from the normal process variability, is introduced by means of a carefully prescribed pattern. The pattern requires that small changes be made in two or three control variables in the neighborhood of the standard operating conditions. Continued manufacture of material under the conditions described by the pattern will allow in-

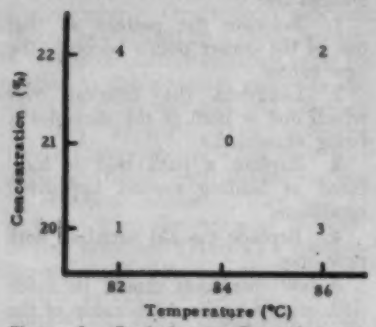


Figure 2. Evolutionary Operation pattern for two controlled variables.

formation to accumulate while material is being produced. To quote from Box, "The effects of the deliberate changes in the variables will usually be masked by large errors customarily found on the full scale. *However, since production will continue anyway, a cycle of variants which does not significantly affect production can be run almost indefinitely, and because of constant repetition the effect of small changes can be detected.*"

The second essential component, **selection,** is supplied by presenting the data gathered to the process supervisor in an easily interpretable way so that changes toward improved manufacture can be made. Box suggests an Information Board. In general, accumulated data are continuously recorded on a board in the process supervisor's office in such a way that he can, at any moment, determine the advisability of moving the pattern, the cost of the program, etc.

At Cyanamid we adopted the form proposed by Box with few modifications. In a number of cases we have taken advantage of the experience of

Phase I — Cycle 7

RESPONSE		YIELD			% IMPURITY		
REQUIREMENT		MAXIMUM			MINIMUM		
Running Averages	CONC (%) 22	525		490	3.8		4.7
	CONC (%) 21		530			4.1	
	CONC (%) 20	540		531	3.8		4.4
		82	84	86	82	84	86
		Temperature (°C)			Temperature (°C)		
95% ERROR LIMITS		± 20			± 20		
Effects With 95% Error Limits	Temp.	-11.0	± 10		0.38	± 0.29	
	Conc.	-14.0	± 10		0.08	± 0.29	
	C × T	6.5	± 10		0.08	± 0.29	
	Change In Mean	6.8	± 18		0.06	± 0.52	
STANDARD DEVIATION		25.9			8.75		

Figure 3. The "Information Board" where the data for the problem are tabulated.

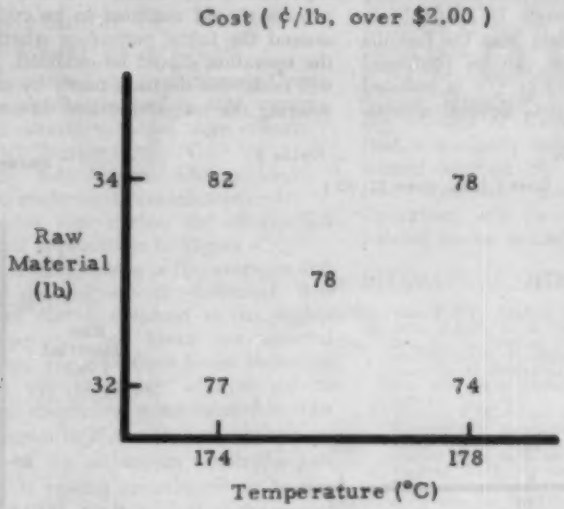
quality control engineers, and have posted the Information Boards in the manufacturing areas. There have been examples where yields have increased merely because interest in the operation was evidenced.

Details of the method

To discuss the detail of Evolutionary Operation, consider an example. As already mentioned, the first important aspect of Evolutionary Operation is that changes in control variables are made according to a prescribed pattern. Figure 2 shows a pattern for two controlled variables.

Position 0 represents the standard operating conditions of temperature and concentration. Positions 1, 2, 3, and 4 represent changes in the two

Phase I — Cycle 4



SOURCE	EFFECT		95% ERROR LIMITS
Temperature	-1.75	±	1.60
Raw Materials	2.25	±	1.60
T. × R. M.	-0.25	±	1.60
C. I. M.	-0.20	±	2.86

Figure 4. The Information Board as it appears after four cycles in Phase I.

variables, considered to be small with respect to their effect on two responses, yield, and percent impurity. If this is a batch process, batches will be made successively at each of the five positions in the order 0, 1, 2, 3, 4, 0, 1, 2, 3, 4, and so on. Each set of five runs is known as a cycle. When convenient to do so, the order in which batches are produced is usually randomized.

In the example in Figure 3, the program is still in Phase I, that is, the pattern is still operating about the original standard conditions. Seven cycles have been completed. At the top of the table are the responses being considered and the requirements for each. Below that appear the running averages calculated through the seventh cycle. The running averages are posted in such a way as to make the relationship between the variables as clear as possible. Since these averages are estimates of the true response under the given conditions, it is essential that a measure of their reliability be available. A measure of this reliability is provided by the 95% error limits. These limits are calculated by the formula $\pm ts/\sqrt{n}$, where n is the number of cycles completed, s is the estimated standard deviation, and t is the appropriate quantity chosen from a table of the t-distribution. A variety of probability levels is available in the table. It is clear from the formula that the program can be continued until the quantity $ts/\sqrt{n}$ is reduced to any desired size. Several alternative procedures for estimating the standard deviation are give in reference (3).

Following this are the effects and their 95%-error limits. If the average at any point, i, is denoted by $\bar{y}_i$, the effects and the error limits may be calculated by the following formulas:

Source	*Effect*	*Error Limits*
Temperature	$1/4(\bar{y}_2+\bar{y}_3-\bar{y}_1-\bar{y}_4)$	$\pm ts/2\sqrt{n}$
Concentration	$1/4(\bar{y}_2+\bar{y}_4-\bar{y}_1-\bar{y}_3)$	$\pm ts/2\sqrt{n}$
Interaction	$1/4(\bar{y}_1+\bar{y}_2-\bar{y}_3-\bar{y}_4)$	$\pm ts/2\sqrt{n}$
Change in Mean	$1/5(\bar{y}_1+\bar{y}_2+\bar{y}_3+\bar{y}_4-4\bar{y}_0)$	$\pm 2ts/\sqrt{5n}$

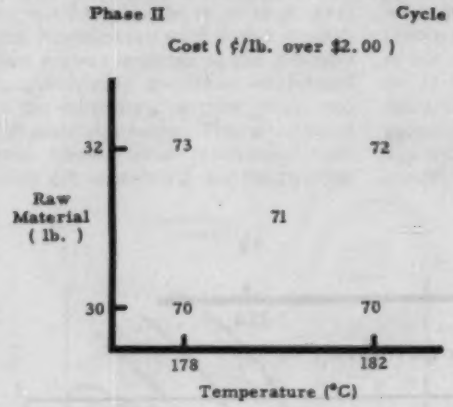
The numerical value of the temperature and concentration effects approximate the change in the response when the conditions are shifted from the center position to either the high or low level. The interaction effect measures the dependence of the two variables. Finally, the change in mean, which is merely the difference between the average of all the runs and the average at the center conditions, measures the change in the average response due to introducing Evolutionary Operation.

On the basis of the data supplied on the Information Board, the process supervisor can decide whether the process should continue to be cycled around the initial pattern or whether the operation should be modified. He will make this decision partly by considering the magnitude and direction of the effects of the variables relative to the error limits. These error limits supply a rough yardstick against which the reliability of any conclusion can be checked. For example, the limits ±20 imply roughly that the values, 530, 490, etc., are *good* to this degree of accuracy (more precisely, that this event, *i.e.*, average equals 530, 490, etc., has a probability of greater than 5% for all hypothesized values of the true mean that lie within the interval defined by the 95%-error limits). Similarly, the effect, −11, associated with temperature, is in the same sense *good* to ±10. The 95% level of probability is, of course, an arbitrary level of certainty, the choice of which depends entirely on the environment.

If the process supervisor decides to modify the operation, several possible choices are:

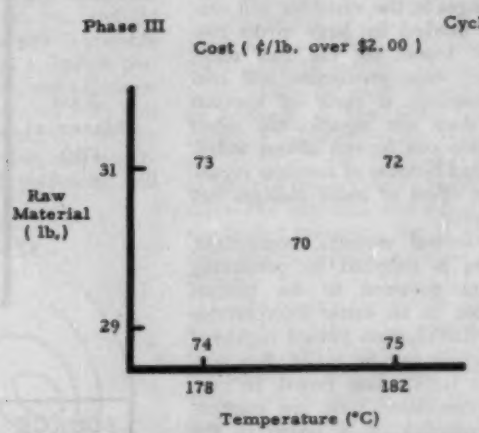
1. Relocate the pattern so that one of the corner points becomes the new center.
2. Lengthen the interval over which one or both of the variables is being examined.
3. Explore a path that is indicated as leading toward improving conditions.
4. Replace the old variables with new ones.

A few comments should be made with regard to the relationship of the effect recorded to the surface of the response variable. If the surface in the locale of Evolutionary Operation pattern is planar, it is completely described by the two main effects. In



SOURCE	EFFECT		95% ERROR LIMITS
Temperature	-0.25	±	1.10
Raw Material	1.25	±	1.10
T. × R. M.	-0.25	±	1.10
C. I. M.	0.20	±	1.97

Figure 5. As Phase II appeared on the Information Board after seven cycles.



SOURCE	EFFECT		95% ERROR LIMITS
Temperature	0	±	1.46
Raw Material	-1.00	±	1.46
T. × R. M.	-0.50	±	1.46
C. I. M.	2.80	±	2.61

Figure 6. The shape of the surface in the locale of the pattern changed drastically from Phases I and II.

this case the path toward improved operation is quite clear. If, on the other hand, a large interaction or change-in-mean effect is found, the assumption of planarity is not tenable. While the running averages will provide hints as to the nature of the nonplanarity, a technique described in reference (2) is used for further exploration.

Concerning the number of variables that can be conveniently run, it has been our experience at Cyanamid that two-variable programs are probably to be preferred for inauguration purposes. However, as production personnel become familiar with the technique, we encourage them to take advantage of the increased efficiency of the three-variable pattern.

Selection of control variables

When it has been agreed that an Evolutionary Operation program should be initiated on a given process, a choice of control variables must be made. As the program proceeds the effect of these variables will decrease as they approach their optimum levels. Consequently, when their possible additional contribution reaches an economic minimum, they will be dropped from the program in favor of new variables. Therefore a continuing supply of ideas regarding possible control variables is essential. For this purpose Box recommends that Evolutionary Operation committees be established.

These committees are comprised of people of different disciplines with interest in the process. The nucleus of such a committee might be the manufacturing personnel, a research chemist thoroughly familiar with the reaction, and a chemical engineer who has had experience with the type of equipment used in the process. The major function of this committee is to advise the process supervisor in the operation of the program. During meetings, held monthly perhaps, for the purpose of interpreting the results, ideas for modification of the program will be generated.

In those areas of production in which we view the performance of Evolutionary Operation as less than ideal, there is one common deficiency —no functioning Evolutionary Operation committees. It has become quite clear that when there is no feedback of ideas to research, when little thought is given to the selection of new variables, the lifeblood of Evolutionary Operation is cut off. The establishment of these committees in all areas heads our list of things to be done.

As an example of the function of the Evolutionary Operation committee in a particular process in which the main reaction was carried out in a large steel tank, one of the conditions of interest was the agitation rate. The agitator, as in most large-scale units, did not have a variable-speed drive, and a capital expenditure to install one for investigative purposes was out of the question. Consequently, the process supervisor decided that agitation could not be examined.

In casual conversation with a chemical engineer of considerable experience, the suggestion was made to insert an air line in the tank and sparge the contents in addition to the normal agitation. This system provides the upper and lower levels of an Evolutionary Operation pattern, and even a center point if the air pressure is regulated. On the basis of this trial, it will become clear whether or not additional money should be spent to allow optimization of the agitation rate. This kind of suggestion cannot be allowed to occur by chance.

People in addition to the nucleus described could periodically contribute to the meetings. An accountant, a statistician, and a person familiar with the quality aspects of the product are examples.

An example of an actual program

In setting up Evolutionary Operation on the product in this example, two control variables were chosen.

1. Temperature, °C
2. Raw Material Charge, Lb.

The response measured was cost.

After four cycles, the information board appeared as in Figure 4.

An examination of the averages and the derived effects indicated that lower cost is obtained at the higher temperature and lower raw material usage. The 95%-error limits indicated that our judgment with regard to these effects had some substance. The apparent lack of curvature in the portion of the surface on which the pattern is resting encouraged us to use the (178°, 32 lb.) point as the upper left point in the new pattern.

After seven cycles, Phase II appeared as in Figure 5.

The effect of temperature had decreased sharply and, when viewed against the error limits, we failed to see any signal with respect to a favorable direction. The raw material effect and error limits on the other hand implied that still lower costs could be obtained by a reduction in the raw material usage.

Peripheral considerations tempered our judgment in relocating the pattern for Phase III. It was known that the stoichiometric amount of the raw material was about 25 lb. However, experience indicated that an excess was necessary. Feeling, therefore, that the critical point might be quite close, the production supervisor suggested that the pattern be shifted downward just one pound.

As seen in Figure 6, this decision was a wise one.

The shape of the surface in the locale of the pattern appeared to have changed drastically from that in Phases I and II. The change in mean effect became quite prominent.

Actually it is important to point out that the five-point pattern is incapable of completely describing the nature of the curvature, and we have in a number of cases augmented the pattern to gain increased information. On this process, however, a long list of variables was waiting to be tried, and it was decided to set temperature and raw material at 180°C and 30 pounds, respectively, and proceed with two other variables.

Conclusion

Our experience with Evolutionary Operation has been gratifying. Unfortunately our program is still too immature to report the over-all economic gain. There is little doubt that it will be considerable. Perhaps it is equally important to point out that the concept of Evolutionary Operation is gradually being instilled as a normal method of production. We feel confident that Evolutionary Operation will be increasingly expanded in our manufacturing area.

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ACKNOWLEDGEMENT

With the help of George E. P. Box and J. Stuart Hunter, the Organic Chemicals Division of Cyanamid instituted Evolutionary Operation in its manufacturing processes in June 1957. This article is a summary of the method described by Box (*1*), and Cyanamid's brief experience.

Chlorination of ilmenite in a fluidized bed

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Titanium and its alloys have assumed great importance in recent years due to their increasing use as corrosion resistant materials. Ilmenite and rutile ores constitute the main raw materials for the production of titanium metal. One widely used process involves chlorination of the ores to titanium tetrachloride and the subsequent reduction of the tetrachloride to metallic titanium.

The chlorination of ilmenite can be accomplished either in a one-step process (*1, 4, 7, 16*) in which iron and titanium are simultaneously chlorinated or in a two-step process (*14, 15, 17*), consisting of the preferential chlorination of iron followed by chlorination of titanium.

The bulk of reported literature on this subject deals with chlorination in a static bed of briquettes composed of ilmenite or rutile (*13*) and a bonding agent. This method is attended by the usual difficulties associated with static bed reactors, viz., channeling, sintering, and poor temperature distribution. In addition, the bonding agent consumes a certain amount of chlorine and the briquettes have a tendency to distintegrate in the reactor. These difficulties can be largely eliminated by conducting the chlorination of the ores in a fluidized bed.

Data reported in the literature on the fluidized bed chlorination of ilmenite pertain almost entirely to the one-step simultaneous chlorination of both the iron and titanium contents of the ore. The reducing agents generally used are either powdered carbon (*2, 3, 5, 12, 18*) or carbon monoxide (*19*). In one patent (*3*) carbon tetrachloride has been mentioned as a combined chlorinating and reducing agent.

The use of powdered carbon as a reducing agent for ilmenite in a fluidized bed tends to result in a segregation of the ore and carbon in the expanded bed due to the density difference between the two solids. A selective carryover of carbon is also likely to occur. Use of gaseous reducing agents such as carbon monoxide may, therefore, be advantageous.

The present investigation was undertaken to study the preferential chlorination of iron in a fluidized bed of ilmenite, using carbon monoxide as the reducing agent.

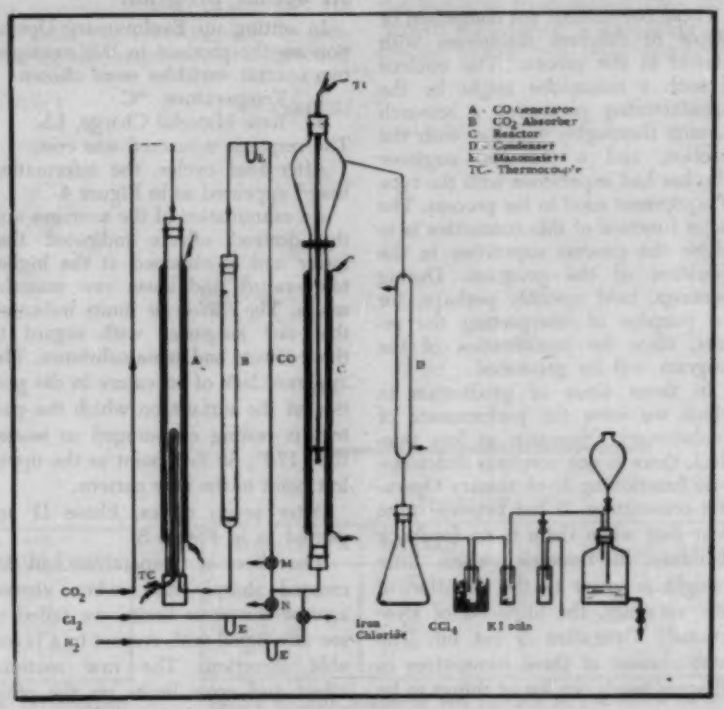

Figure 1. Schematic diagram of apparatus.

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Experimental

Ilmenite used in this investigation was supplied by the Travancore Minerals Ltd., Alwaye. Its composition and sieve analysis are shown in Tables 1 and 2, respectively. The −60+85 fraction was used for the experiments.

A diagrammatic sketch of the experimental assembly is shown in Figure 1. As carbon monoxide cylinders were not available, the gas was prepared from carbon dioxide in an auxiliary reactor. Carbon dioxide from a cylinder entered the carbon monoxide generator (A) which consisted of a 1-in. diam. × 30 in. long vitreosil silica tube heated by means of an externally wound electrical resistance wire and filled with carbon granules. Unconverted carbon dioxide was removed in a scrubbing tower (B) packed with 10-mesh soda lime; CO of over 99% purity was thus available.

The chlorination reactor consisted of a vitreosil silica tube of the same dimensions as the CO generator and was also heated by an externally wound electrical resistance wire. The top of the reactor was connected to a glass cyclone by steel flanges. The ilmenite ore rested at the bottom of the reactor over a 5-in. height of porcelain beads. Provision was made for flushing the reactor with nitrogen and for measuring temperatures along the length of the reactor by means of a traveling thermocouple.

The procedure for carrying out a run was as follows: The heating of the CO generator and chlorination reactor was commenced and a slow stream of N_2 was passed through the reactor to expel any residual moisture or O_2. The required quantity of ilmenite was introduced into the reactor and the flow of N_2 increased in order to keep the ore in a fluidized state and to avoid sintering.

Table 1. Chemical Composition of Ilmenite

Constituent	% By Wt.
TiO_2	62.60
FeO	11.00
Fe_2O_3	23.44
SiO_2	1.40
Rest (V_2O_5, Al_2O_3, etc.)	1.26

Table 2. Sieve Analysis of Ilmenite

Size	% By Wt.
+60	10.0
−60+85	59.0
−85+100	9.0
−100+120	17.0
−120	5.0

The flow of CO from the soda lime tower was adjusted to the required rate and let out into the atmosphere at M; Cl_2 was introduced at the required rate and was removed from the system at the point N. When the reactor reached a steady temperature, the flow of nitrogen was stopped and the two-way cocks at M and N were immediately manipulated to turn the CO-Cl_2 mixture into the reactor.

As the reaction is exothermic, the temperature at the start of a run was kept about 25°C. lower than required. It rose to the desired value in less than a minute and at this stage the heat input was manually controlled to hold the temperature constant.

The reaction products left the reactor through the glass cyclone at the top, passed through a condenser where iron chlorides were removed, and then through an ice-cooled bubbler containing carbon tetrachloride for absorbing chlorine. Any unabsorbed chlorine was fixed in a 10% KI solution. The residual gases were collected for analysis in an aspirator bottle. It may be mentioned that phosgene formation from CO and Cl_2 is negligible in the absence of a catalyst (active carbon).

At the end of each run, the iron chlorides were analyzed for combined chlorine and iron. CCl_4 and the KI solution were analyzed for Cl_2 and the gaseous products for CO and CO_2. An over-all mass balance was made by checking the weight of charge against the combined weights of the residue and iron oxides reacted. The average error was less than 5%.

The total volume of each of the gases in the exit stream during any run, *i.e.*, CO, CO_2 and Cl_2, was determined from a knowledge of the total Cl_2 absorbed, the volume of CO fed, and the analysis of the gas collected after chlorine absorption.

In order to determine whether any TiO_2 in the ore was undergoing chlorination, a few residues were analyzed for TiO_2. It was found that the loss of TiO_2 through chlorination was less than 1%.

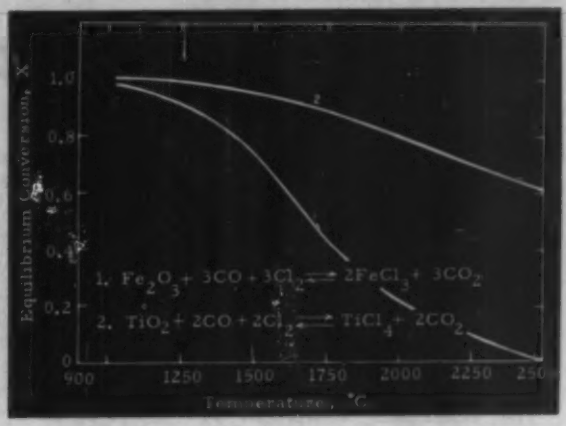

Figure 2. Equilibrium conversions of Fe_2O_3 to $FeCl_3$ and TiO_2 to $TiCl_4$ as functions of temperature.

Results

Iron is present in ilmenite both as FeO and Fe_2O_3. The chlorination of these oxides proceeds according to reactions (1), (2), and (3).

$$2\ FeO + 2\ CO + 2\ Cl_2 = 2\ FeCl_2 + 2\ CO_2 \quad \ldots\ldots\ldots (1)$$

$$2\ FeCl_2 + Cl_2 = 2\ FeCl_3 \quad \ldots\ldots (2)$$

$$Fe_2O_3 + 3\ CO + 3\ Cl_2 = 2\ FeCl_3 + 3\ CO_2 \quad \ldots\ldots\ldots (3)$$

A rigorous approach to the determination of the degree of chlorination of iron in ilmenite would require a knowledge of the extent to which each of the two iron oxides has been chlorinated. Since the $FeCl_2$ formed from FeO tends to be further chlorinated to $FeCl_3$, the degree to which FeO and Fe_2O_3 have individually reacted cannot be ascertained by an analysis of the products for $FeCl_2$ and $FeCl_3$. It would therefore be necessary to analyze the residue for FeO and Fe_2O_3 after each run and even this tedious procedure would

assume negligible reduction of Fe_2O_3 to FeO by CO.

A simpler and more practical method of estimating the degree of chlorination of iron oxides is to determine the extent of the over-all removal of FeO and Fe_2O_3, irrespective of the degree of chlorination of the individual oxides. The over-all chlorination rates can then be expressed in terms of a single oxide.

The amount of chlorine required per gram of FeO is 1.48 g., provided all the $FeCl_2$ is converted to $FeCl_3$ [reactions (1) and (2)], while that required per gram of Fe_2O_3 is 1.33 g. [reaction (3)]. The assumption that all the $FeCl_2$ is converted to $FeCl_3$ is valid (as shown later) except for runs of very short duration. It will thus be seen that the error introduced by assuming the iron to be present as Fe_2O_3 when all of it is present as FeO is 10%. As only a third of the iron in ilmenite is present as FeO, the error involved would be of the order of 3% if all the iron in ilmenite is assumed to be Fe_2O_3. It has therefore been assumed for simplicity in this investigation that iron is present in ilmenite entirely as Fe_2O_3.

The equilibrium conversions of Fe_2O_3 to $FeCl_3$ and of TiO_2 to $TiCl_4$ were calculated at various temperatures and are plotted in Figure 2. It is seen that the reverse reactions are negligible both for TiO_2 and Fe_2O_3 at temperatures below about 1000°C. Also, at temperatures up to about 1000°C, it is possible to remove the entire quantity of Fe_2O_3 from ilmenite, the kinetics of the two reactions controlling the extent of the preferential chlorination of Fe_2O_3. Beyond this temperature, the reverse reaction in the case of Fe_2O_3 is accelerated to such a degree that the chlorination of Fe_2O_3 at equilibrium becomes decreasingly preferential. Even if the rate of chlorination of Fe_2O_3 is accelerated to a greater extent than that of TiO_2, the degree of chlorination of Fe_2O_3 at higher temperatures is limited by the equilibrium conversion of Fe_2O_3.

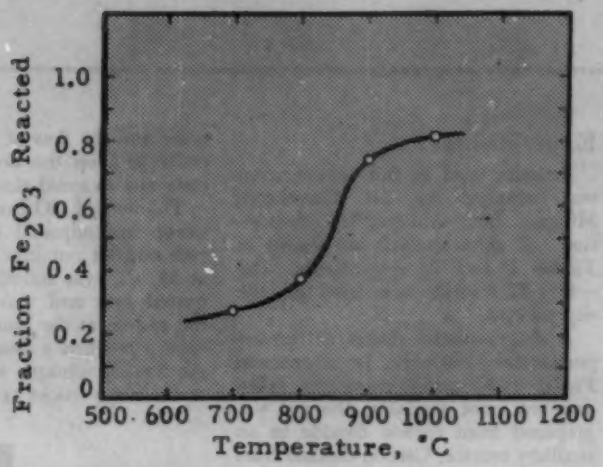

Figure 3. Effect of temperature on chlorination of Fe_2O_3 in ilmenite.

Preliminary experiments. A few runs were made to determine the effect of temperature on the preferential chlorination of iron oxides. The rate of total gaseous feed ($CO + Cl_2$) was fixed at 910 cc./min. which was considerably higher than the minimum rate for effective fluidization of a 50-g. charge of ilmenite. The gas volumes are expressed at S.T.P. throughout this paper. The ratio of CO to Cl_2 was held constant at 1.5, and runs were made at various constant temperatures ranging from 700 to 1000°C. Results are shown in Figure 3. It is evident that the conversion increases sharply with temperature up to about 900°C. Beyond this temperature, although the equilibrium conversion would tend to fall, no reduction in conversion was noticed in our experiments as the maximum temperature used did not exceed 1000°C. The nature of Figure 3 also suggests that there is perhaps a change in reaction mechanism around 750°C.

One of the factors affecting the degree of chlorination is the ratio of CO to Cl_2 in the gaseous feed. To study this variable, a series of runs was

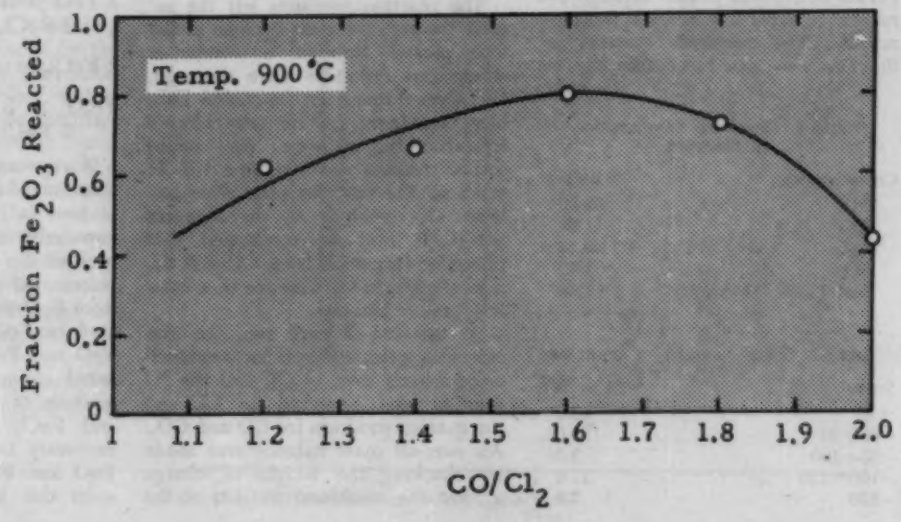

Figure 4. Effect of ratio of CO to Cl_2 in feed on chlorination of Fe_2O_3.

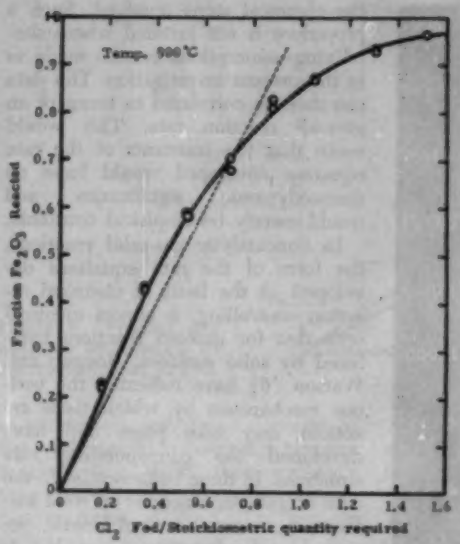

Figure 5. Chlorine requirement as a function of Fe_2O_3 reacted.

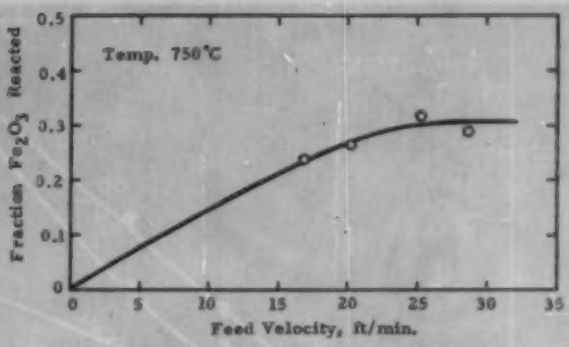

Figure 6. Effect of feed velocity on chlorination of Fe_2O_3.

made with a 50-g. charge of ilmenite at 900°C. The rate of gaseous feed was maintained at 910 cc./min. The amount of Cl_2 was fixed at the quantity theoretically required [Equation (3)] for the chlorination of all the iron in ilmenite, the rate of CO and duration of run being varied to obtain different ratios of CO to Cl_2 at a constant total volumetric feed rate. The results are shown in Figure 4. It is seen that there is an optimum permissible ratio of CO to Cl_2 in the feed which is about 1.6.

Another series of runs was made to determine the effect of the amount of chlorine fed on the degree of chlorination of the iron oxides. In these runs, the ratio of CO to Cl_2 was held constant at 1.6, and 75 g. of charge were fluidized at a total gaseous feed rate of 1040 cc./min. and at 900°C. The amount of chlorine fed was varied by making runs of various durations. The experimental data are plotted in Figure 5.

Up to the stage where the amount of chlorine fed is below about 70% of the theoretical requirement, Figure 5 indicates that the Fe_2O_3 reacted exceeds the theoretical quantity calculated from Equation (3). This discrepancy can be explained as follows: during the early stages of chlorination, FeO is chlorinated to a much larger extent than Fe_2O_3 and the $FeCl_2$ formed does not undergo further chlorination to $FeCl_3$. It was observed, for example, that in a run of 5-min. duration at 900°C, the amount of $FeCl_2$ formed constituted 82% of the total iron chlorides produced. On the other hand, no $FeCl_2$ was formed in the product after a run of 45-min. duration. It would therefore appear that in runs of short duration, reaction (1) predominates and the discrepancy arises out of the fact that all calculations in the present investigation have been based on the assumption that chlorination occurs according to reaction (3), irrespective of the duration of a run.

The amount of chlorine required increases rapidly as the fraction of Fe_2O_3 left in the bed decreases. Figure 5 shows that for the removal of about 97% of Fe_2O_3, almost 1.5 times the stoichiometric requirement of chlorine is necessary.

Effect of mass transfer. In most of the investigations reported in the literature on the kinetics of solid-gas reactions in fluidized beds (*8-11*), mass transfer did not materially affect the reaction rates. Kivnick and Hixson (*8*), working on the reduction of nickel oxide, showed that mass transfer has a significant effect on reaction rates. Wetherill and Furnas (*22*) observed that mass transfer influences the kinetics of iron ore reduction by hydrogen and carbon monoxide in a fixed bed.

At low gas velocities, the fluid film surrounding the solid particles is likely to offer considerable resistance to the transport of reactants and products between the bulk of the gas stream and the solid surfaces, particularly for cases where the chemical reaction is rapid. For this reason, rate data involving fixed beds are usually

continued

Table 3. Effect of Mass Transfer on the Chlorination of Iron Oxide

Duration of run:	20 min.
W/F:	1,610
Temperature:	750°C.
Ratio of CO to Cl_2:	1.6

Run No.	Cl_2 Rate cc./Min.	CO Rate cc./Min.	Velocity of Total Gaseous Feed Ft./Min.	Wt. of Charge G.	Wt. of Fe_2O_3 Reacted G.	Wt. of Residue G.	Overall Mass Balance Error, %	Fe_2O_3 Reacted Wt. Fraction
53	270	430	16.83	50	4.3	45.12	−1.16	0.239
61	320	510	20.20	60	5.68	59.96	−0.60	0.263
36	400	640	25.24	75	8.55	66.34	−0.15	0.319
65	455	725	28.60	85	8.85	75.35	−0.94	0.290

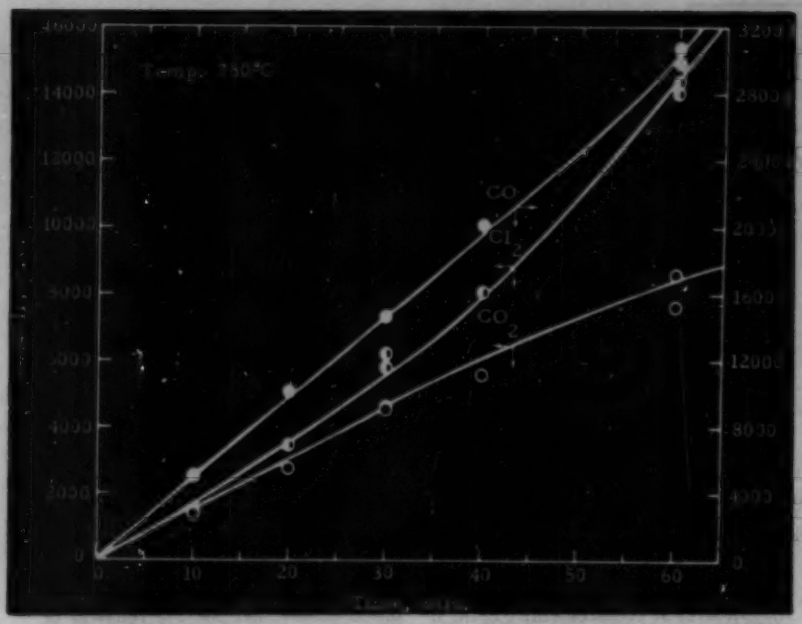

Figure 7. Product gas volumes as function of reaction time at 750°C.

obtained at velocities high enough to eliminate mass transfer effects. Use of such high velocities is, however, often impractical in fluidized beds.

A series of runs was made to determine whether mass transfer influenced the reaction rate in the present investigation. These experiments were conducted at 750°C and at a CO/Cl_2 ratio of 1.6. The weight of ilmenite and the gaseous feed rate were independently varied from 50 to 85 g. and 16.83 to 28.60 ft./min., respectively, while maintaining a constant initial W/F ratio of 1610. Data are presented in Table 3 and plotted in Figure 6.

Figure 6 indicates that at low velocities, the conversion increases appreciably with increase in velocity while beyond a velocity of about 25 ft./min., it is substantially independent of velocity. This should also be true at higher temperatures since a flow rate corresponding to 25 ft./min. at 750°C would give higher velocities at higher temperatures. Apparently, the effect of mass transfer on reaction rate is significant only at the lower velocities.

According to the two-phase concept of fluidization proposed by Toomey and Johnstone (*21*), gas-solid fluidized beds can be divided into a dense phase and a disperse phase. Part of the gas generally passes through the bed in pockets or channels which collectively form the disperse phase while the rest of the gas supporting the bed constitutes the dense phase. At the velocity of incipient fluidization there is no disperse phase, but as the velocity is increased the amount of gas in excess of that required for incipient fluidization gives rise to the disperse phase while the gas stream moving at the velocity of incipient fluidization constitutes the dense phase. Shen and Johnstone (*20*) suggest that the increase in over-all reaction rate with velocity may be attributed to the effect of gas velocity on mass transfer between the two phases.

It has been observed in the present investigation that the reaction rate does not increase indefinitely with velocity as would conceivably be the case if mass transfer between the two phases of fluidization were the controlling mass transfer step, but tends to reach a practically constant value at velocities above about 25 ft./min. This indicates that resistance to diffusion across the film surrounding the solid particles is perhaps the controlling mass transfer step and not mass transfer between the two phases of the fluidized bed as suggested by Shen and Johnstone (*20*). Detailed attempts have not been made to study mass transfer effects in this investigation.

Kinetic analysis. Any study of the mechanism of a complex reaction would involve the development of various rate equations and selection of the most plausible one for each of the chemical steps involved. Such a procedure is not justified where simplifying assumptions can be made as in the present investigation. The data can then be correlated in terms of an over-all reaction rate. This would mean that the constants of the rate equation developed would have no thermodynamic significance and would merely be empirical constants.

In noncatalytic gas-solid reactions, the form of the rate equations developed on the basis of chemical reaction controlling, is almost identical with that for gaseous reactions catalyzed by solid surfaces. Hougen and Watson (*6*) have indicated the various mechanisms by which these reactions may take place and have developed the corresponding rate equations. In these equations, as in the case of gaseous reactions on solid surfaces, there are the usual kinetic, potential, and adsorption terms, but in addition there is a term (A_m) for the interfacial reactive surface area of the solid. In noncatalytic gas-solid reactions, where the solid participates in the reaction, A_m changes as the reaction progresses; it would therefore be necessary to express A_m as a function of conversion in order that the rate equation may be useful.

In the present complex reaction it is not possible to express A_m in terms

Table 4. Experimental Kinetic Data

Run No.	Temp. °C.	Duration of Run Min.	Linear Gas Velocity Ft./Min.
K1	900	30	28.96
K2	"	30	"
K3	"	25	"
K4	"	25	"
K5	"	20	"
K6	"	20	"
K7	"	15	"
K8	"	15	"
K9	"	10	"
K10	"	10	"
K11	"	5	"
K12	"	5	"
K13	825	35	27.10
K14	"	35	"
K15	"	25	"
K16	"	25	"
K17	"	15	"
K18	"	15	"
K19	"	5	"
K20	"	5	"
K21	750	60	25.24
K22	"	60	"
K23	"	40	"
K24	"	30	"
K25	"	30	"
K26	"	20	"
K27	"	10	"

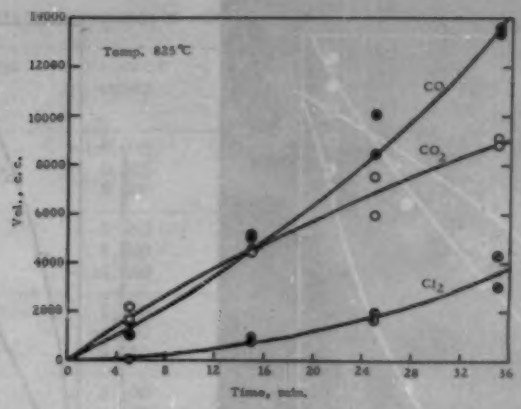

Figure 8. Product gas volumes as function of reaction time at 825°C.

of conversion, but if the decrease in the solids weight is taken into account in evaluating W/F, then we shall have a method of expressing conversion in terms of W/F. The various values of W/F are obtained by determining W at different process times, F being held constant. This is identical with varying the catalyst weight for obtaining different values of W/F in a catalytic integral reactor as against the more common procedure of varying F at constant W.

In steady-state catalytic flow reactions, the conversion under given conditions is independent of time but in the present batch reactor conversion changes progressively with time. At the beginning of a run, when process time is zero, W is equal to the initial weight of iron oxide in the bed; F being constant throughout the run, W/F has the maximum value at the start of the run. From the general nature of the conversion vs. W/F curves for catalytic reactions, it can be readily seen that the reaction rate is lowest at this point. The highest value of reaction rate would be obtained in the final stages of a run when W/F has a very low value.

In the development that follows, chlorine will be considered as the key component and the reaction rate (r) expressed as gram-moles Cl_2 reacted per unit weight of iron oxide per minute. By a mass balance across a differential width of bed at any instant of process time, one obtains

$$rdw = Fdx \qquad (4),$$

$$\text{or } W/F = \int_0^x (1/r)dx \qquad (5).$$

Unlike gaseous reactions catalyzed by solid surfaces, where Equation (4) holds for an entire run under fixed operating conditions, in this case W, x and r all vary with process time but at any instant, the mass balance represented by Equation (4) is satisfied. Thus, if r can be expressed in terms of a Langmuir-type rate equation, W can be calculated from Equation (5) by integration of the term $(1/r)$ between appropriate limits.

If the instantaneous partial pressures of CO, CO_2 and Cl_2 in the exit stream can be determined by a continuous automatic method, or a known amount of gas collected over a period of $\Delta\theta$ minutes and the partial pressures of the gases assumed to be the instantaneous values at time $\theta + \Delta\theta/2$, these values may be directly used for correlation. Another method whereby the instantaneous partial pressures of the gases may be computed is by determining the instantaneous volumes of the gases by graphical differentiation of the experimentally determined volume-time curves. This last method is the most convenient for small-scale

Total feed rate: 1040 cc./min. Wt. of ilmenite: 75 g. Ratio of CO to Cl_2: 1.6

Fe_2O_3 Reacted G.	Weight of Residue G.	Overall Mass Balance Error, %	Weight Fraction Fe_2O_3 Reacted	Total Volume in Exit Gases cc. At S. T. P.			Partial Pressure in Exit Gases mm. Hg.		
				Cl_2	CO_2	CO	P_{Cl_2}	P_{CO_2}	P_{CO}
23.50	51.36	−0.2	0.870	1145	8710	10490	41.4	315.2	379.6
23.63	50.68	−0.92	0.875	1210	9380	9820	43.7	338.5	354.3
22.46	51.46	−1.44	0.830	360	8700	7300	16.2	390.3	327.5
21.92	52.40	−0.92	0.812	500	8700	7300	22.4	389.4	326.8
19.05	55.70	−0.33	0.705	188	7206	5591	10.7	408.8	317.4
18.30	56.00	−0.66	0.678	280	6451	6349	15.9	366.1	360.2
15.92	58.90	−0.24	0.590	40	5175	4425	3.1	397.2	339.6
15.70	59.10	−0.27	0.582	20	5332	4088	1.5	425.1	313.0
11.72	62.80	−0.64	0.434	5	3968	2432	0.6	457.6	280.5
11.54	62.90	−0.76	0.427	5	4211	2189	0.6	485.9	252.5
5.95	68.40	−0.88	0.220	5	2170	1030	1.2	502.4	238.4
6.23	68.26	−0.68	0.231	3	2163	1037	0.7	501.2	240.3
20.80	53.69	−0.68	0.770	3026	9093	13307	89.4	268.5	393.1
20.00	54.42	−0.78	0.741	4299	8826	13584	120.7	247.8	381.3
15.36	58.91	−1.08	0.569	1962	5952	10048	82.5	250.1	422.3
18.30	56.16	−0.72	0.678	1615	7520	8480	68.5	319.0	359.7
12.57	61.75	−0.92	0.465	773	4570	5030	55.6	328.7	361.8
12.76	61.32	−1.24	0.433	937	4426	5174	66.6	314.6	367.7
5.26	68.92	−1.17	0.195	13	2163	1037	3.0	504.0	241.6
5.10	69.61	−0.40	0.189	25	1658	1542	5.8	384.8	357.9
16.60	55.50	−3.90	0.615	14000	7616	13784	199.5	108.6	438.7
18.25	55.63	−1.50	0.680	14360	8553	29847	201.9	120.3	419.8
14.16	60.87	0.04	0.598	8030	5530	20070	179.6	123.7	448.7
11.10	63.54	−0.48	0.411	5780	4510	14690	173.8	135.6	441.6
13.60	63.05	2.20	0.504	6190	4610	14590	183.1	136.3	431.5
8.55	66.34	−0.15	0.317	3438	2777	10023	158.8	128.2	462.8
4.52	70.44	−0.06	0.167	1510	1390	5050	142.8	131.4	477.5

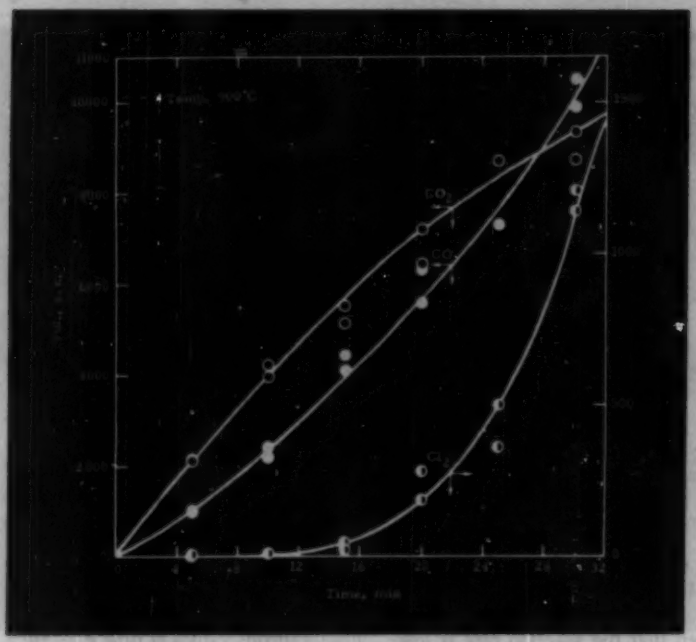

Figure 9. Product gas volumes as function of reaction time at 900°C.

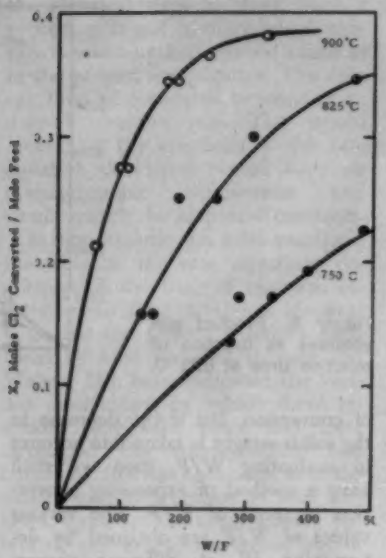

Figure 10. Instantaneous conversion of Cl_2 as a function of W/F.

laboratory reactors and has been used in the present study. The amount of chlorine reacting at any instant is calculated from the feed rate and the instantaneous unconverted chlorine. From this the conversion, x (moles Cl_2 reacted/per mole feed), can be computed. Reaction rate, r, can then be obtained by graphical differentiation of the W/F vs. x curve.

Kinetic data and correlation. Runs were made at three temperatures, 750, 825 and 900°C. The total feed rate was held constant at 1040 cc./min. At this rate the gas velocities at 750, 825 and 900°C were 25.24, 27.10 and 28.96 ft./min., respectively. It is clear from Figure 6 that the influence of mass transfer is negligible at these velocities. Kinetic data obtained at a feed rate of 1040 cc./min. would therefore be independent of mass transfer effects. The ratio of CO to Cl_2 was maintained at 1.6 and the weight of ilmenite charged was 75 g. for each run. The only variable for any series was the duration of run, which was varied from 5 to 60 min. The experimental data are shown in Table 4.

In Figure 7 the volumes of the product gases, CO, CO_2, and Cl_2, are plotted as function of reaction time at 750°C. Similar curves for 825 and 900°C appear in Figures 8 and 9, respectively. The instantaneous partial pressures of the gases were obtained by graphical differentiation of the curves of Figures 7-9. In Table 5 are summarized the values of p_{CO}, p_{CO_2} and p_{Cl_2} and the corresponding values of x at various times. Figure 10 is a plot of x vs. W/F. Differentiation of the curves of Figure 10 gave the values of the reaction rate, r, for various values of W (or W/F) as shown in Table 5.

The rate data have been correlated in the following manner. It is reasonable to assume that the rate of reaction would be proportional to the

Table 5. Summary of calculated results.

Wt. of ilmenite: 75 g.
Total feed rate, F: 0.0465 g.-moles/min.
Ratio of CO to Cl_2: 1.6

Duration of run min.	Temperature °C.	Cl_2 converted moles/mole feed	Iron oxide in bed (W)* g.	W/F	Reaction rate $r.10^4$	Instantaneous partial pressures p_{CO}	p_{CO_2}	p_{Cl_2}
10	750	0.225	22.48	484	8.96	0.455	0.290	0.312
20	750	0.198	18.45	397	4.13	0.432	0.276	0.348
30	750	0.171	15.90	341	4.37	0.417	0.255	0.383
40	750	0.135	12.84	276	4.64	0.401	0.222	0.433
5	825	0.346	21.80	470	2.11	0.455	0.533	0.066
15	825	0.300	14.30	308	4.58	0.547	0.374	0.129
25	825	0.250	11.64	250	6.72	0.596	0.274	0.184
35	825	0.157	6.20	133	8.95	0.629	0.187	0.231
10	900	0.381	15.40	332	0.526	0.432	0.563	0.006
15	900	0.365	11.15	240	2.71	0.500	0.488	0.031
20	900	0.344	8.00	172	6.40	0.525	0.415	0.070
25	900	0.275	4.65	100	14.20	0.560	0.291	0.149
30	900	0.212	2.80	60	20.60	0.592	0.206	0.203

*Average values of two (or more) runs.

Table 6. Temperature dependence of rate constants.

Rate const.	Temperature °C.	Value of const.	Slope of Eq. (7) $-E$	Intercept of Eq. (7) A
k	750	0.023		
	825	0.323	39,000	7.73×10^{14}
	900	3.000		
k_1	750	2.280		
	825	6.820	15,300	7.05×10^{6}
	900	14.300		
k_2	750	1.100		
	825	4.100	16,200	1.02×10^{7}
	900	9.150		
k_3	750	2.100		
	825	5.460	13,600	1.32×10^{6}
	900	10.800		

partial pressures of the two gaseous reactants, CO and Cl_2. Further, as the entire development presented above is based on the assumption that the solid may be regarded as a catalyst though it participates in the reaction, the data should be amenable to a type of correlation that includes an adsorption term. At the temperatures under consideration, the reverse reaction can be neglected (Figure 2). Also, in order for the rate equation to be useful, it should contain only those partial pressure terms which can be readily evaluated from the exit gas stream. Accordingly, $FeCl_2$ has not been considered in calculating p_{CO}, p_{CO_2} and p_{Cl_2}. For a given temperature, an equation of the form,

$$r = \frac{k\, p_{CO}\, p_{Cl_2}}{(1 + k_1\, p_{CO} + k_2\, p_{CO_2} + k_3\, p_{Cl_2})^2} \qquad (6),$$

was found to fit the data well. The average deviation for each temperature was of the order of 5 percent.

The values of the rate constants appearing in Equation (6) for the three temperatures are recorded in Table 6. It was found that these constants could be correlated with temperatures (Figure 11) by an Arrhenius-type equation,

$$k = Ae^{-E/T} \qquad (7).$$

The values of the intercept A and slope E for the four constants are presented in Table 6. It can be seen from Figure 11 that the rate constant, k, appearing in the numerator of Equation (6), increases rapidly with temperature. The constants, k_1, k_2 and k_3, also increase slightly with temperature. This is contrary to the usual behavior of adsorption constants appearing in the denominator of a rate equation. As has already been pointed out, this is due to the fact that Equation (6) is empirical and these constants have consequently no thermodynamic significance.

The correlations presented may be verified by calculating r from Equation (6) using the values of the constants obtained from Equation (7) and evaluating W/F from Equation (5) by graphical integration. The values of W obtained in this manner are plotted against the experimental values at the corresponding process times in Figure 12. It can be seen that the agreement is good, the average error being about 8% and maximum error 18%.

Graphical determination of W/F is often tedious and may be substituted by analytical integration of Equation (6), provided that the resulting expression is not too cumbersome to use.

Assuming that the reaction proceeds entirely according to Equation (3), p_{CO}, p_{CO_2}, p_{Cl_2} can be expresed in terms of a (moles CO/min.), b

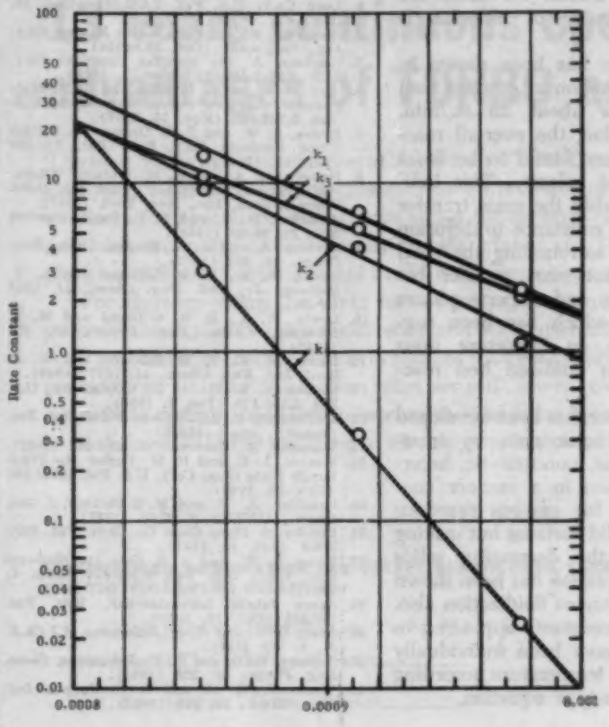

Figure 11. Relationship between rate constants and temperature.

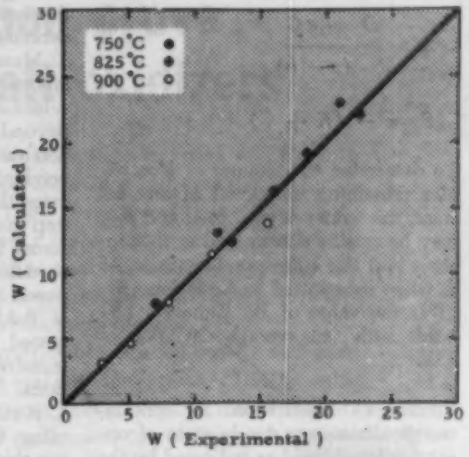

Figure 12. Comparison of experimental values of W with those calculated from Eqs. (5) and (6).

(moles Cl_2/min.) and x. Substituting the rate equation, written in terms of these values, in Equation (5) and integrating between the limits x and 0, one obtains,

$$W/F = B^2x - \frac{E}{(a+b)} \ln (a - \overline{a+b}\, x) - \frac{F}{(a+b)} \ln (b - \overline{a+b}\, x) + \frac{E}{(a+b)} \ln a + \frac{F}{(a+b)} \ln b \quad (8)$$

where

$$A = \frac{(a+b) + k_1 a + k_2 b}{\sqrt{k}}$$

$$B = \frac{k_2 - (1 + k_1 + k_2)}{\sqrt{k}}$$

$$C = 2AB + B^2 (a+b)$$

$$D = A^2 - B^2 ab$$

$$E = \frac{D + aC}{-(a-b)}$$

$$F = -(E + C)$$

To determine the amount of iron oxides remaining unreacted at any instant, the values of p_{CO}, p_{CO_2} and p_{Cl_2} may be readily determined at that instant and the corresponding value of x, when substituted in Equation (8), gives the value of W. Equation (8) holds with an average deviation of 11%.

Continuous fluidization. In continuous fluidization a steady state of operation is achieved as indicated by the conversion reaching a constant value that is determined solely by the operating variables and not by process time. The weight of Fe_2O_3 in the ore stream, and therefore the value of W/F, are constants for an entire run as in the case of any catalytic reaction. The partial pressures of CO, CO_2, and Cl_2 in the exit gases will also be independent of time.

Let W_1 be the weight of Fe_2O_3 in the bed in a given continuous fluidization run at steady state and r_1 the reaction rate. Then the partial pressures of CO, CO_2, and Cl_2 would in effect be identical with the instantaneous partial pressure values for a batch fluidization run at a process time corresponding to an Fe_2O_3 weight of W_1 in the bed and a reaction rate of r_1. Thus the rate equation developed for batch fluidization using instantaneous partial pressures can also be used for continuous fluidization. Conversely, a rate equation can be developed with a continuous fluidization reactor by making a plurality of runs, each run giving fixed values of W (in bed), p_{CO}, p_{CO_2}, p_{Cl_2} and x. The curve of W/F vs. x can then be directly established as in the case of any catalytic reaction. The rate equation thus developed can be used to predict the value of W at any instant in a batch reactor.

Summary

1. The chlorination of iron oxides in ilmenite has been accomplished without any particular difficulty by using CO as reducing agent in a batch fluidization reactor.

2. The optimum conditions for the preferential chlorination of iron oxides have been determined: ratio of CO to Cl_2 in feed, 1.6; temperature of chlorination, 900°C. To remove about 97% of iron oxides, almost 1.5 times the theoretical quantity of chlorine is necessary.

3. Mass transfer has been shown to influence the reaction at gaseous feed velocities below about 25 ft./min. Beyond this value, the over-all reaction rate has been found to be independent of feed velocity. This indicates that probably the mass transfer step involved is resistance to diffusion across the film surrounding the solid particles and not mass transfer between the dense and disperse phases of fluidization which has been suggested *(20)* as an important mass transfer step in fluidized bed reactions.

4. A rate equation has been developed using batch reactor data by treating this solid-gas, noncatalytic, heterogeneous reaction in a manner analogous to that for gaseous reactions catalyzed by solid surfaces but making allowance for the decreasing solids weight. This equation has been shown to hold for continous fluidization also. The four rate constants appearing in the equation have been individually correlated with temperature according to an Arrhenius-type equation.

ACKNOWLEDGMENT

Thanks are expressed to the Director, National Chemical Laboratory, for permission to publish the results of this investigation.

NOTATION

A = intercept of Eq. (7).

A_m = surface area of reacting solid/unit volume.

a = CO in feed, g.-moles/min.

b = Cl_2 in feed, g.-moles/min.

E = slope of Eq. (7).

F = total feed rate, g.-moles/min.

k, k_1, k_2, k_3 = constants of Eq. (6).

p_{CO}, p_{CO_2}, p_{Cl_2} = partial pressures of CO, CO_2, and Cl_2, respectively, atm.

r = reaction rate, $dx/d(W/F)$, moles Cl_2 reacted/g. iron oxide in bed/min.

T = temperature, ° K.

t = temperature, ° C.

W = weight of iron oxide in bed, g.

x = chlorine conversion, moles Cl_2 converted/mole total feed.

x^* = equilibrium conversion, moles reacted/mole.

θ = time, min.

$\Delta\theta$ = a finite interval of time, min.

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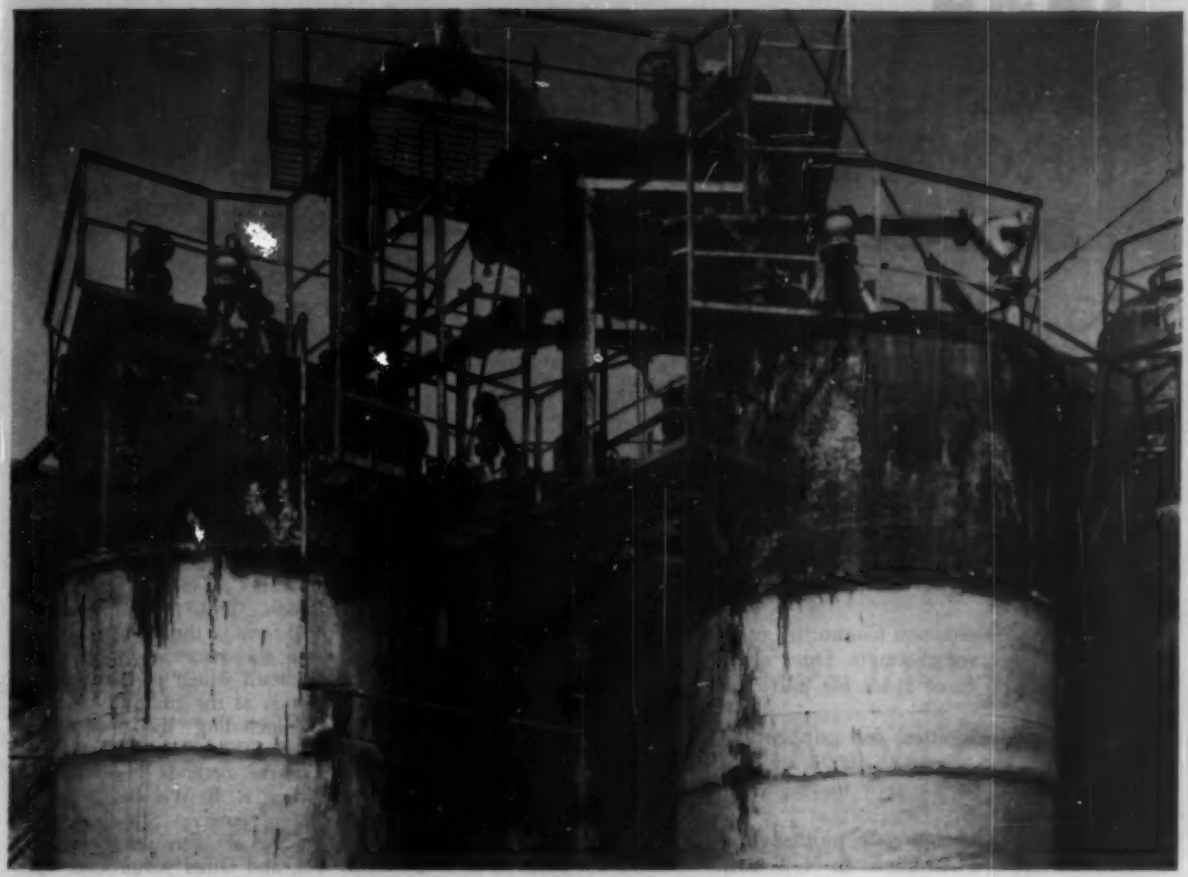

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CEP

COMPUTER PROGRAM abstracts

Based on the interest which has been expressed to date, the Machine Computation Committee is proceeding to have the following manuals prepared, reviewed, and published:

Abstract No.	Program	Computer	Contributor
006	Line Sizing	IBM 650	McKee
018	Liq.-Liq. Heat Exchanger Design	IBM 650	Esso Res.
020	Multicomponent Distillation	Datatron 205	Dow
016	Non-Linear Estimation	IBM 704	IBM

The Machine Computation Committee of the A.I.Ch.E. is interested in receiving program abstracts. Once again the Committee wishes to emphasize the three rules for participation in the interchange program:

1) Abstracts submitted for publication must follow the form published in *CEP* (January, 1959) and in the *Guide*.

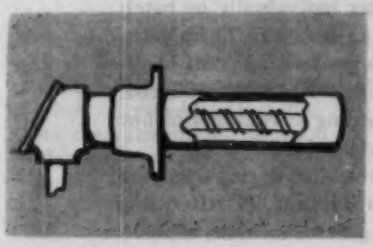
2) Abstracts must be sent to the Machine Computation Committee c/o A.I.Ch.E.

3) All questions relating to published abstracts must be sent to the Committee c/o A.I.Ch.E. in New York.

Resistance Temperature Tables (024)

L. H. Krone
Monsanto Chemical Company
Applied Mathematics Section
St. Louis, Missouri

Description: The program calculates R_t, the resistance of a platinum re-



sistance thermometer at t°C, from the equation $R_t = R_0 [1 + At - AD (.01\ t-1)(.01\ t) - kAB(.01\ t-1)(.01\ t)^3]$.

Data required include the calibration constants R_0, A, B, and D, as well as the temperature range and temperature increment to be used in developing the table.

Computer: IBM 704, 4K core.
Program language: Fortran II.
Running time: Table is printed on-line at 75 lines per minute (printer limited). Each line includes ten increments. Timing formula is approximately

$(t_2-t_1)/(750\Delta t)$ minutes,

where t_1 and t_2 specify the range and Δt is the increment size.
Comments: Three modifications of the formula are available.
These are:

1) $k = 1$ for all values of t
2) $k = 0$ for all values of t
3) $k = 1$ if $t < 0$; $k = 0$ if $t \geq 0$.

Availability: The manual on this program can be made available for publication should sufficient interest develop.

Solution of the Brunauer, Emmett and Teller Multimolecular Adsorption Equation (027)

Walter Meyer
Chemical Engineering Department
Oregon State College, Corvallis, Oregon

Description: To correlate adsorption data, and to determine the area of commercial adsorbents, the multimolecular adsorption equation of Brunauer, Emmett, and Teller (BET) is often applied. The equation as usually applied is a special form of the general equation which assumes that 4, 5, or an infinite number of layers of gas molecules are adsorbed on the adsorbent surface. The use of this equation when it is not strictly applicable can lead to appreciable errors in the calculation of adsorbent surface area. To apply the general or *n* form of the BET equation, however, was a tedious time consuming trial and error process. This program solves the general form of the BET equation determining the number of molecular layers adsorbed which permits direct determination of the constants of the equation, including the adsorbent surface area. The computer solution is based on the methods presented by L. G. Joyner, E. B. Weinberger, and C. W. Montgomery, "Surface Area Measurements of Activated Carbons, Silica Gel, and Other Adsorbents," *J. Am. Chem. Soc.*, 47 (1945), 2182-2188.
Computer: IBM 650, Basic machine.
Program language: Bell Laboratories Interpretive System.
Running time: The machine time required is approximately three minutes.
Comments: The program has been used successfully to determine the value of the constants of the BET equation for the adsorption of various halogenated gases on alumina, silica gel, and carbon.
Availability: The manual on this program can be made available for publication should sufficient interest develop.

TRAP—Tape Regression Analysis Program (IBM 650—Tape) RAPA—Regression Analysis Program (Augmented IBM 650) RAP—Regression Analysis Program (Basic IBM 650) (028)

J. E. Nichols
Shell Oil Company
Houston Research Laboratory
Houston 1, Texas

Description: This program will compute most of the mathematical and statistical functions desired in the

continued on page 92

Electro-Hydraulic Valve Actuators

by **GPE Controls** offer the simplest, most compact, lowest-cost way to operate control valves from an electric signal. Model 698 shown positions 1¼" double-seated valve at 1000 p.s.i. pressure drop, with input signal ranges of 1-5, 4-20, or 10-50 ma. Completely self-contained. Easy, low-cost installation. Position repeatability within .002". Automatic locking with power failure simplifies start-up of process. Division I construction for hazardous service is standard. Other models available for heavier duty.

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The right ratio of surfaces—the right materials—the right velocities—the right proportion between coil area and depth . . . there are dozens of factors that affect the efficiency, maintenance and service life of heat-exchange coils.

For best performance in your own application, the practical approach is to take full advantage of the unequalled engineering, research and design skill — the unequalled manufacturing and testing facilities — which Aerofin offers you.

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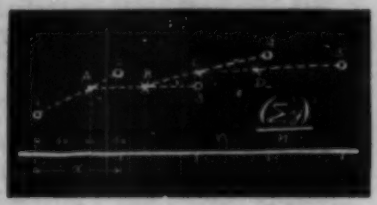
Aerofin is sold only by manufacturers of fan-system apparatus. List on request.

For more information, turn to Data Service card, circle No. 16

Computer programs

from page 90

fitting of data to mathematical equations. Conventional least squares techniques are used. Matrix inversion is done by Gaussian elimination. TRAP output contains the following: 1) original least squares matrix; 2) inverse least squares matrix; 3) a set of constants and coefficients for each dependent variable; 4) total variation; 5) variation by regression; 6) correlation coefficient; 7) error variance and standard deviation; 8) "F" and "T"



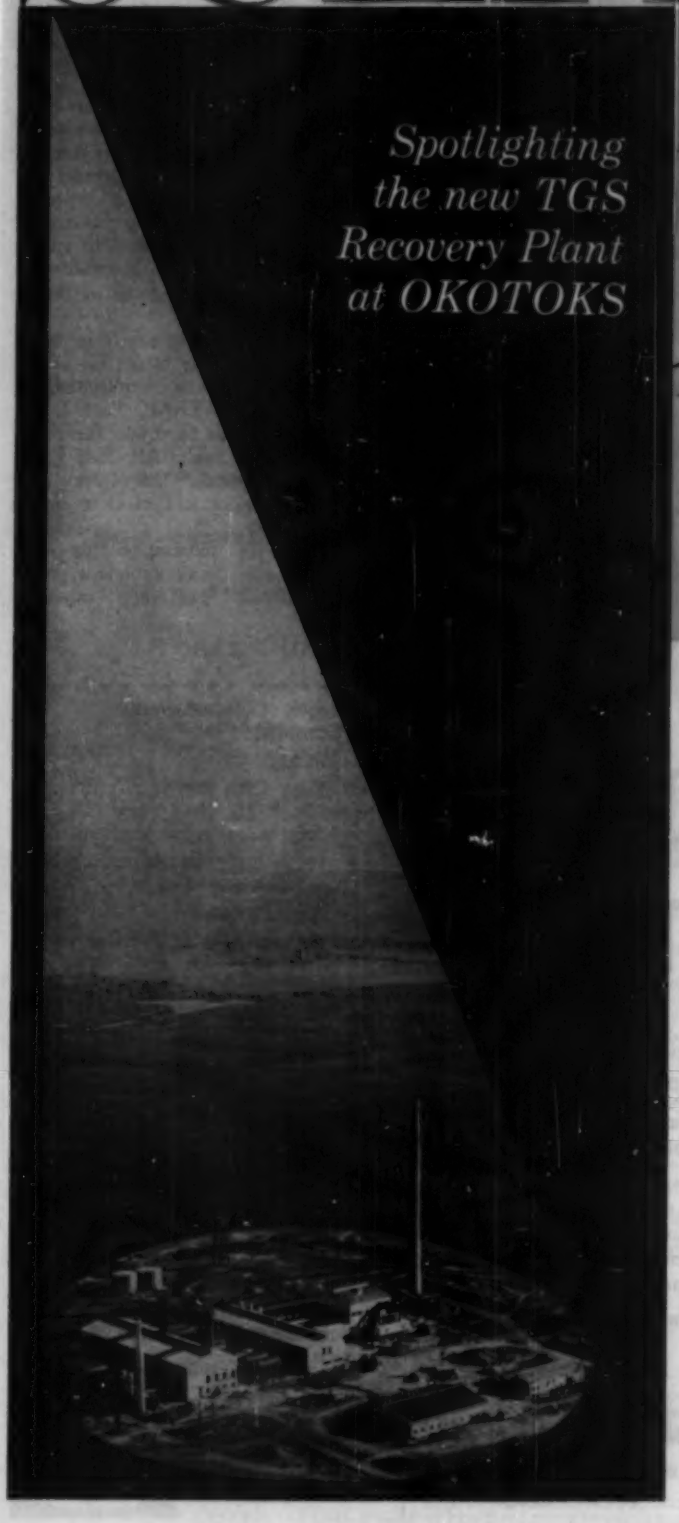
test values for each term; 9) table of residuals for each observed and calculated dependent variable; 10) sum of residuals squared; 11) chi-square test values; and 12) variance check to indicate roundoff errors, if any. RAPA and RAP output do not contain items 9, 10, 11, and 12, and RAP is further limited by not containing items 4, 5, and 6 in the above list.

The programs provide for the entry of thirty-two variables and up to 999 observations. Nine dependent variables can be correlated in one pass in the TRAP and RAPA programs while eight is the maximum number in the RAP program. The regression equation to be fitted may contain a maximum of twenty-six terms including dependent variables. Each term may be the product of up to five transformed variables all raised to various powers ranging from 0.1 to 9.9. Variable transformations are done by means of codes and constants. The programs provide for thirty-two constants and thirty-two codes. Data are entered as positive and/or negative, four-digit floating decimal numbers. The automatic floating decimal device is used by TRAP and RAPA programs, and RAP uses the programmed floating decimal arithmetic in SIR (Symbolic Interpretive Routine).

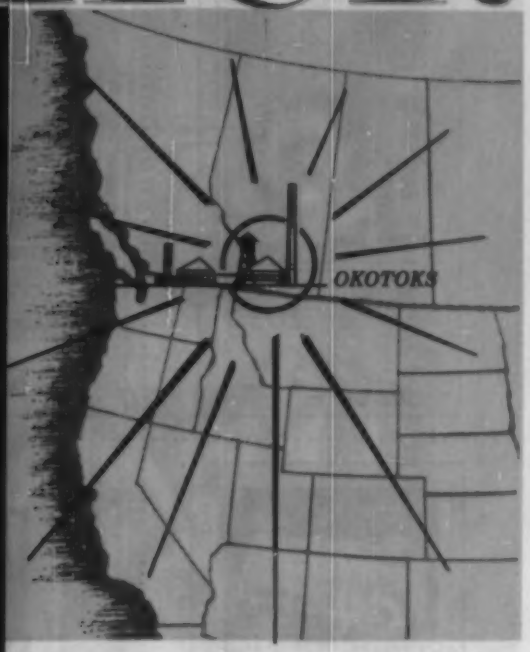
Computer: TRAP — Augmented type 650 with alphabetic device, index accumulators, automatic floating decimal device, 60 words of core storage, attached 407 printer, and one 727 magnetic tape unit.

continued on page 94

SULPHUR



Spotlighting the new TGS Recovery Plant at OKOTOKS



OKOTOKS marks another step in the steadily broadening service being developed by TGS for industries in the States and Canada. Production from OKOTOKS, sitting on top of the vast "sour gas" field a few miles south of Calgary, Alberta, will add a significant tonnage to the supplies of Sulphur already available through TGS to the expanding industries in the Pacific Northwest. OKOTOKS is set up to make shipments of Sulphur in solid or molten form.

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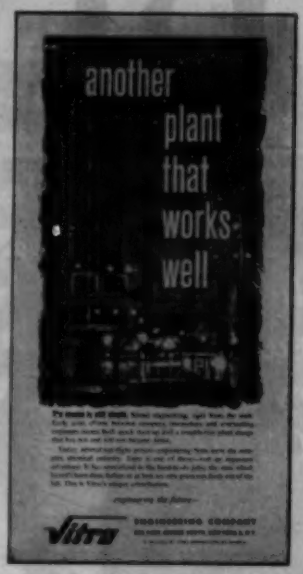

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Computer programs

from page 92

RAPA–Same as above except no tape unit.
RAP–Basic type 650 with alphabetic device.

Program language: SOAP II.
Running time: The running time of each program is a function of equation size, the number of observations, and the number and type of transformation of the variables. A typical TRAP program for 11 observations of 6 independent and 3 dependent variables requiring 3 transformations using the log and exponential routines required 2½ minutes.
Comments: Each program is in two parts. The availability tables for each part indicate storage requirements. The output from TRAP, Part I, is stored on magnetic tape and the output from RAPA and RAP, Part I, is punched into cards. The output of Part I is the input to Part II in each case.
Availability: The manual on this program can be made available for publication should sufficient interest develop.

Machine Computation Committee
A.I.Ch.E.
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New York 36, New York

I am interested in computer program manuals corresponding to the following abstracts:

- ☐ (027) Solution of the Brunauer, Emmett and Teller Multimolecular Adsorption Equation
- ☐ (028) TRAP, RAPA and RAP Regression Analysis Programs
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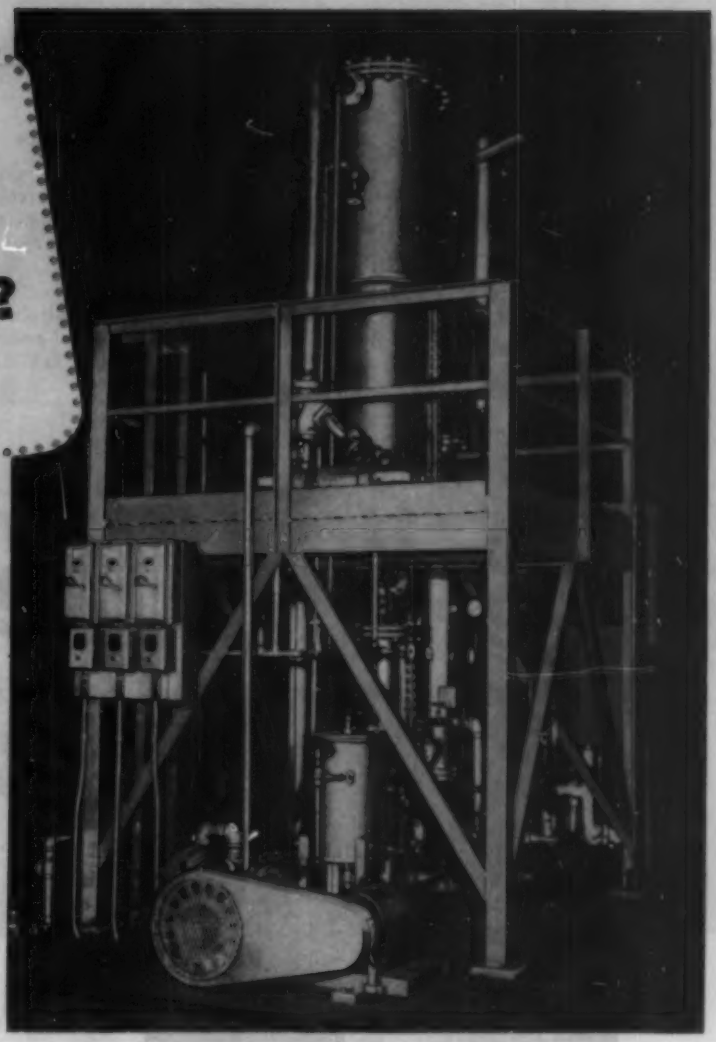

CB&I pilot plant facilities are available for determining heat transfer coefficients on unknown materials. Typical evaporator-crystallizer unit at right provides valuable data for design of processing equipment.

In the design of heat transfer units, such as multiple effect evaporators and crystallizers, there is no substitute for experience and equipment. This is why so many *companies with heat transfer problems* bring them to CB&I.

Here, CB&I's expert chemical engineering staff—using pilot plant facilities—tackles each problem on an individual basis. The result: custom-designed heat transfer equipment to meet specific requirements.

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For more information, turn to Data Service card, circle No. 141

Molecular film evaporation control

A patent has just been issued for a practical method of controlling water evaporation with molecular films. Potential saving—$3-8 an acre foot of water.

Practical application of the principle of molecular films to a reservoir control evaporation process moved one step nearer with the granting of a U.S. Patent to Russell G. Dressler for his "Suspension Process." The process, applying fatty alcohol as a water suspension, was first announced at the A.I.Ch.E. meeting in December 1957, at Chicago. (*CEP*, January 1958, pp 66-69)

Essence of the method is that finely divided, pre-wetted fatty alcohol particles are activated when in this form and disperse into films from 20,000 to 100,000 times faster than the same material in flake or other common forms. Addition of material is continuous, but in very small amounts. Chief difficulty with previous methods was that the film formation was too slow to cope with losses due to the film's wind drift, so that continuous coverage could not be maintained over the reservoir.

Experimental applications on outdoor reservoirs show that this process can save from 35% to 60% of the water normally lost by evaporation. Preferred material is stearyl alcohol (octadecanol).

Application

Tests show that the best technique for applying the process on reservoirs up to 330 acres is to spread the water suspension using pumps and orificed distribution lines laid along the upwind shoreline. One hundred percent surface coverage can thus be maintained continuously under severe wind conditions. Savings of 63% have been attained in some of the trials on outdoor reservoirs. This is the maximum obtained under controlled tests in laboratory equipment. For small reservoirs, the material is dripped onto the water surface from containers set at intervals along the shore line.

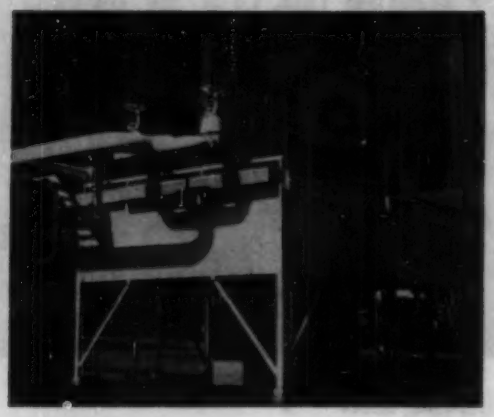
It is expected that water evaporation control will find widespread use on water bodies of the arid regions of some 15 western states where losses range from four to ten feet of water a year.

This new usage for fatty alcohols may create an ultimate market of ten to forty million pounds a year in this country alone.

Using the pump and distribution line technique, projected studies indicate that on reservoirs of 5,000 to 50,000 acres in size, the cost of saving water is expected to be about $3.00 to $8.00 an acre foot.

A liquid alum plant to be built at Stauffer's Vernon, California, works is scheduled for completion late this year. Capacity of 1000 tons a month will supply the pulp and paper and water purification industries of Southern California.

Hi Fi SET?



Yes, SMITHCO Air Cooled Heat Exchangers DO have Hi Fidelity — they are engineered to provide faithful service long after others have ceased to operate.

A SMITHCO Heat Exchanger compares in other ways with a precision built Hi Fi set. For example, you wouldn't buy a Hi Fi in which all electrical connections were merely wrapped instead of one with conventional soldered connections, would you? Well, then, it follows that you wouldn't buy a heat exchanger with the fins wrapped instead of soldered to the tube.

SMITHCO is the ONLY major manufacturer of air cooled heat exchangers with solder bonded fin tubes. This solder bond assures the highest efficiency of heat transfer between fin and tube and has proven to be the most permanent bond yet devised.

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Send for Processing Profiles, the authoritative new color booklet of performance reports! It shows Swenson products on the job . . . bringing higher efficiency and quality to all the processing industries. Remember, what Whiting's Swenson Evaporator Division has done for others can be done for you. *Swenson Evaporator Company, 15690 Lathrop Avenue, Harvey, Illinois.*

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High rates of heat transfer, a cinch to clean—and just like old Uncle Remus—dependable. When it comes to pushing BTUs around you just can't beat Heliflow.

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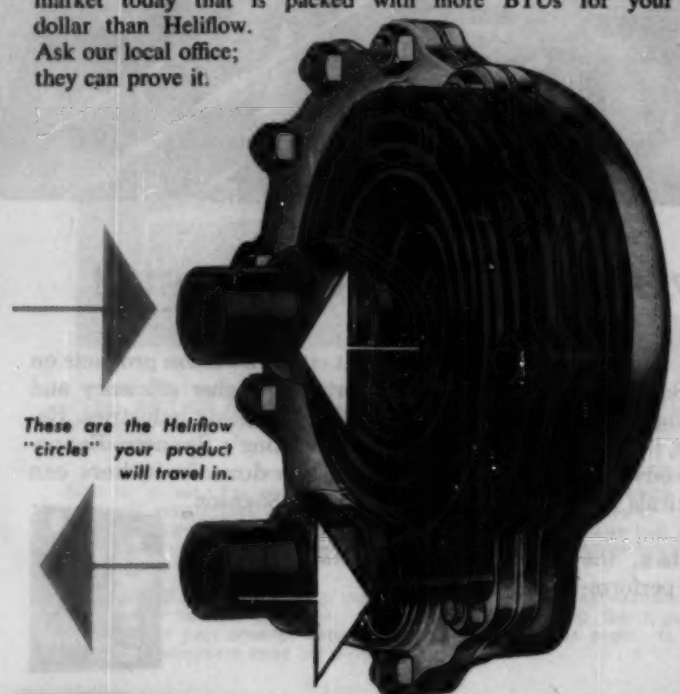
Seriously, though, we defy you to find any exchanger on the market today that is packed with more BTUs for your dollar than Heliflow.
Ask our local office;
they can prove it.



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The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions. These names are listed in accordance with Article III, Section 3 of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Members and Associate Members will receive careful consideration if received before November 15, 1959, at the office of the Secretary, A.I.Ch.E., 25 West 45th Street, New York 36, N. Y.

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Wilson, Thomas H., *Columbia, S. C.*

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Cook, Dale M., *Argo, Ill.*
Crooks, John L., *Sandusky, Ohio*

Davis, Ronald E., *Hoover, Ohio*
Donigulan, Ted M., *South Pasadena, Calif.*

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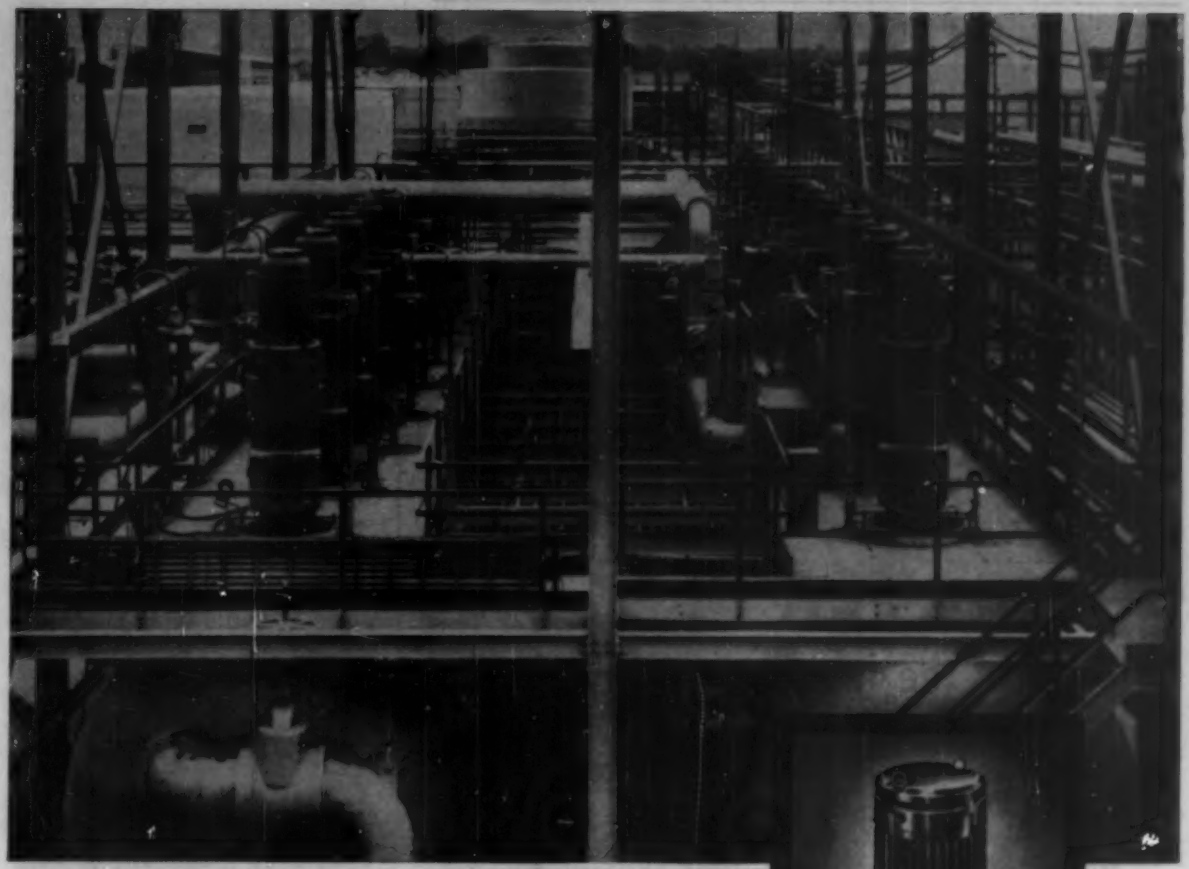
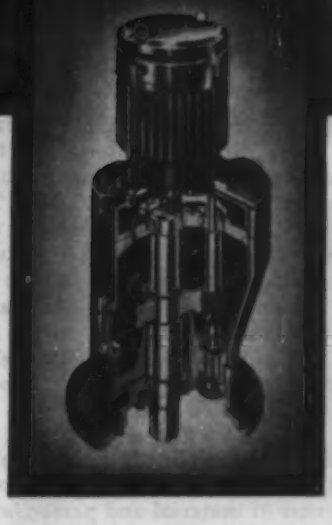


50 HP Philadelphia Mixers in continuous operation...



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FIRST. In any comparative evaluation of mixers having equivalent torque capacity, a Philadelphia Mixer will *always* have the largest, heaviest duty, highest capacity bearings . . . and the drive with the best bearing support for shafting will have the truest running shaft.

SECOND. Because the bearings in Philadelphia Mixers are larger, the diameter of the output shaft is larger . . . and the design which has the largest diameter shaft will have least shaft deflection from hydraulic loads imposed on the mixing impeller during operation.

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from page 98

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Holste, Hilary E., *Chesrick, Pa.*

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Wisley, H. W., *Akron, Ohio*

Yandle, Jack E., *Oklahoma City, Okla.*

Zaremba, Z. K., *South Charleston, W. Va.*

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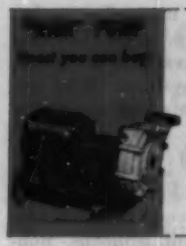

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industrial news

Engineering Index aids chemical engineers

A solution to the problem of access to the rapidly mounting volume of publications in engineering is offered by the Engineering Index. It helps the engineer locate new data, and generally keep up with technological developments.

A comprehensive indexing and abstracting service, the Index editorial staff annually reviews over 1,500 periodicals and society transactions, as well as a large number of bulletins and reports of government bureaus, schools, institutes and research organizations. Over 30,000 articles in all languages and branches of engineering are summarized.

For each article reviewed, the following information is given on a 3 x 5 library card: subject classification, name and date of publication, title of article and name of author, and a brief summary of the article.

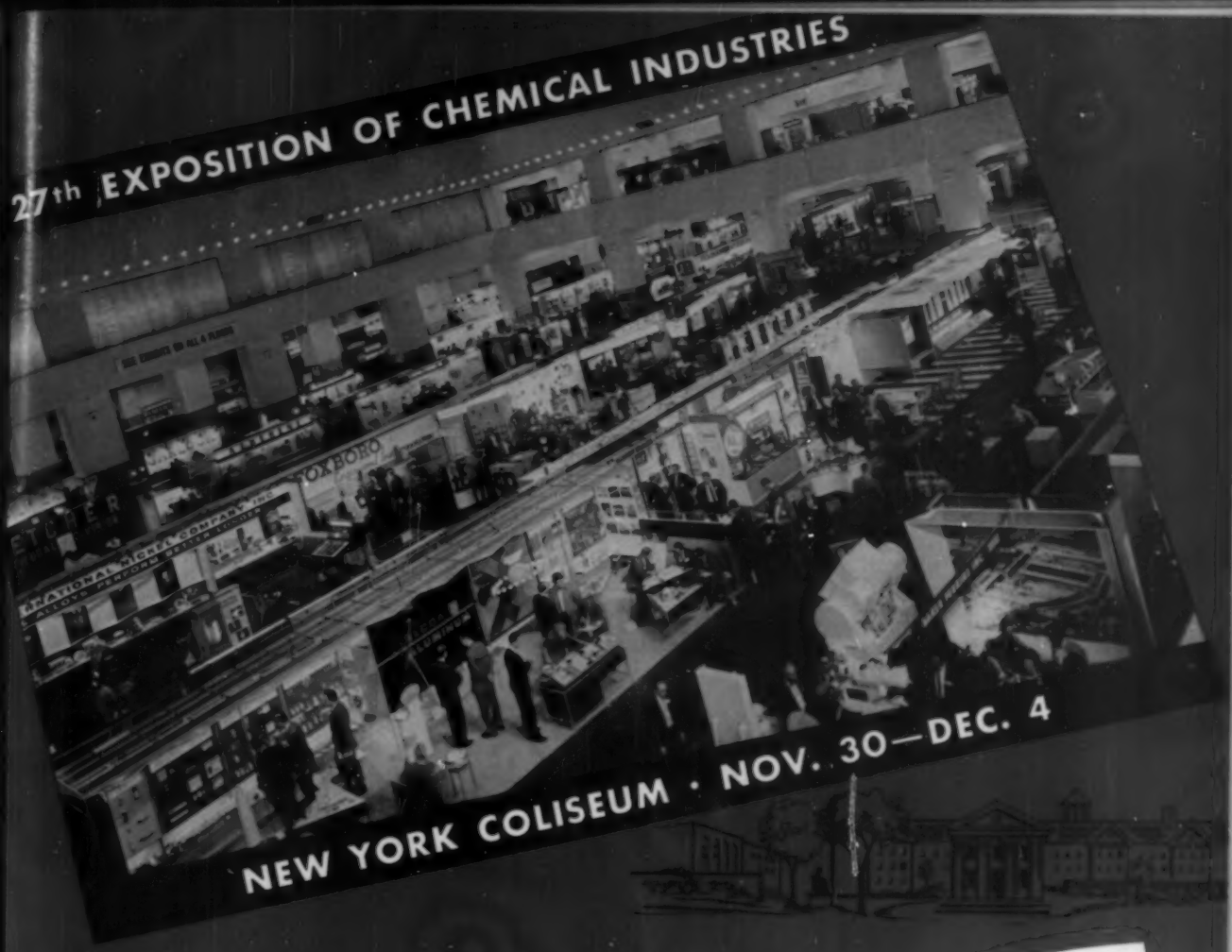
The service is divided into 249 "Field of Interest" divisions. The user can select as much or as little as he needs. The subscriber who wants information only in certain areas may take the divisions he needs. Subscribers to individual divisions receive all pertinent abstracts once a week, while those who get the complete service receive their abstracts daily. Subscriptions are taken on a single subject, or for groups of divisions.

The Index service cards appear annually as a bound volume, containing all the references for the year. This volume, now in its 75th year, is an internationally accepted digest of technological literature prepared for engineers, research workers and students.

An increase in rated capacity of the acetylene derivatives plant of General Aniline & Film is underway at Calvert City, Kentucky. Increased demand for polyvinylpyrrolidone and various intermediates required in its synthesis, brought about the expansion which will incorporate recent technological advances into existing units.

Expansion of Ubatol polymer emulsion production will take place at UBS Chemical when the recently acquired A. E. Staley division adds to the facilities at the Lemont, Illinois, plant. Contract for the work has been awarded to Badger.

For more information, circle No. 131 ▶



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Glass—Optical
Glassware
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Grinders
Heat Exchangers
Heaters and Heating Equipment
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Hoods, Fume
Indicators
Instruments, Optical
Instruments of Precision
Instruments, Testing
Insulating Material—Heating, Electric and Molded
Insulation, Furnace
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Kettles
Kilns
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Laboratory Apparatus and Supplies
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Sieves, Laboratory
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Tubing
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industrial news

4th National Heat Transfer Conference

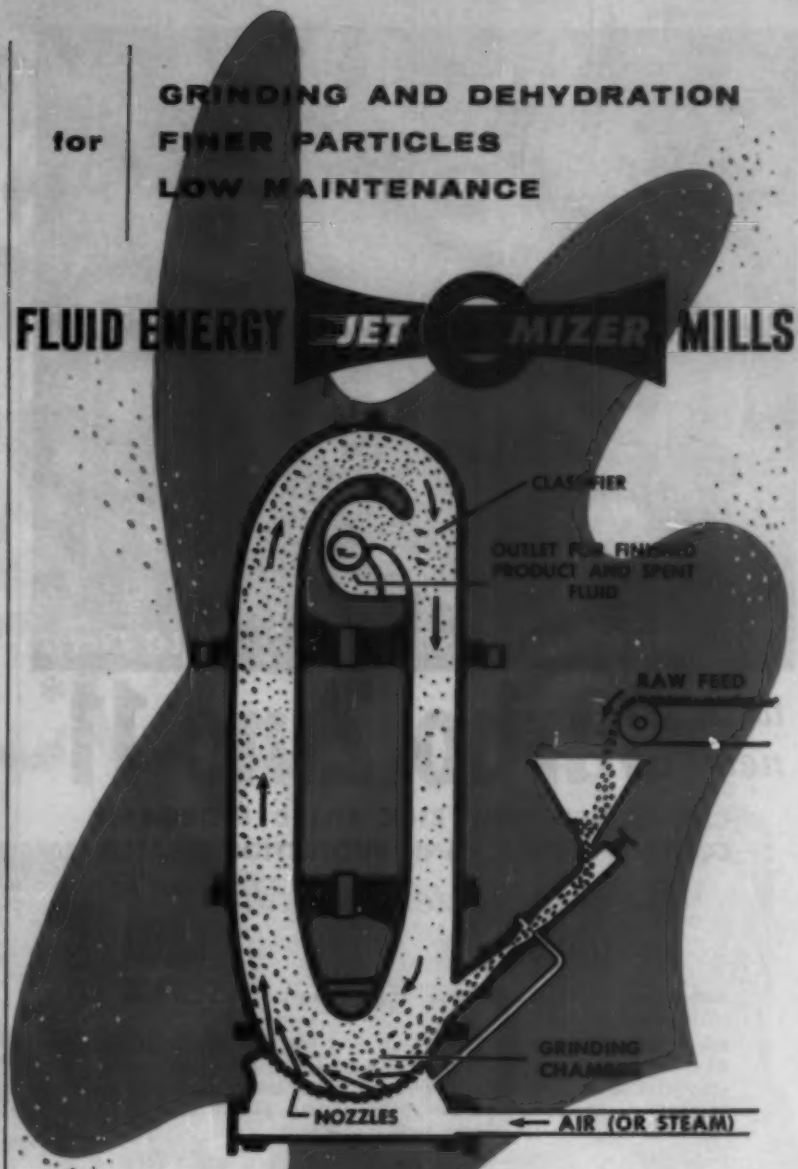
A date has been set for the 1960 National Heat Transfer Conference. The conference and exhibit, fourth in a series jointly sponsored by A.I.Ch.E. and ASME, will be held in Buffalo, New York, on August 14-17. Those Institute members who wish to submit papers to the conference can do so through S. W. Churchill, University of Michigan, Ann Arbor, Michigan. ASME members' papers will go through J. P. Hartnett, University of Minnesota, Minneapolis, Minnesota. For information on the exhibit, write to American Institute of Chemical Engineers, 25 West 45th Street, New York 36, N.Y.

New solvent plant completed by Delhi-Taylor has capacity up to 2500 barrels a day of narrow distillation range solvents. Included are heavy aromatic solvents, and aliphatic and specialty solvents. The unit is expected to provide closer control of feed stocks for high purity and uniformity.

A facility for the processing of commercial power reactor fuels will be designed and engineered at Vitro's Hanford Works under a $4 million contract awarded Vitro Engineering by AEC. It will reprocess up to 150 tons a year of fuel element materials, and will be capable of handling fuel elements including oxide and alloy cores clad with aluminum, zirconium, and stainless steel. Operations are planned to begin in early 1961.

for GRINDING AND DEHYDRATION
FINER PARTICLES
LOW MAINTENANCE

FLUID ENERGY JET-O-MIZER MILLS



The Fluid Energy "Jet-O-Mizer" Mill is designed and built by the pioneers in fluid energy fine grinding. Does far more than produce fine particles. It controls fineness and product quality with a narrow distribution range and simultaneously with grinding can dehydrate, coat particles, blend and achieve chemical changes.

Jet-O-Mizer Mills are being used all over the world, processing many types of materials in the following industries:

• Abrasive	• Food	• Pigment	• Wax
• Insecticide	• Mineral	• Plastic	• Metal
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"Jet-O-Mizing" produces FINE PARTICLES ¼ micron average and above PLUS . . . Narrow Particle Distribution • Dry, or Controlled Moisture Content • Continuous Operation • Uniformity of End Product • Other Operations with Grinding • No Attritional Heat — No Moving Parts • Low Operating Costs • Low Maintenance

Send for complete information on Fluid Energy's "Jet-O-Mizer" Mills, "Jet-O-Clone" Dust Collectors, and TESTING AND CUSTOM GRINDING services.

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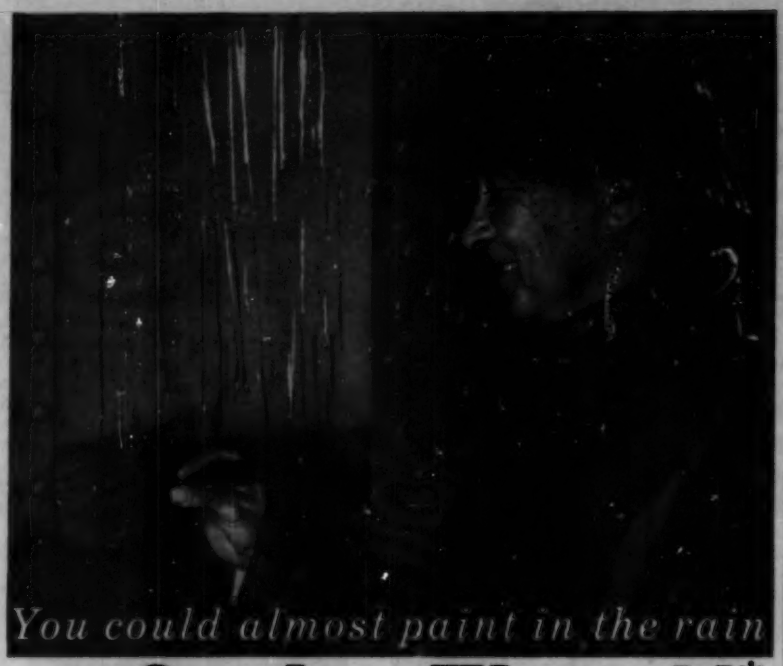
(Formerly known as the Wheeler-Stephenoff Mill)

For more information, turn to Data Service card, circle No. 29



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CARBOLINE'S NEW ZINC FILLED *INORGANIC* COATING FOR GALVANIC PROTECTION OF STEEL

Becomes water insoluble 20 minutes after application

Sudden rainfall, night condensation or rising tide will not wash it off or affect curing.

Carbo Zinc 11 is not only a new coating, it is a new *concept* in zinc filled inorganic coatings, with desirable properties not found in other protective coatings. In only 20 minutes the coating becomes insoluble in water. It can be applied directly to damp surfaces, in 90-100% humidity and at temperatures as low as 0°F.

***Only one coat* provides long-lasting galvanic protection to steel surfaces in marine, coastal and offshore environments. It is also insoluble in organic solvents, and is highly recommended for lining of solvent storage and cargo tanks. And look at its other outstanding characteristics:**

- **Prevents subfilm corrosion**
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- **Does not blister — cures from inside out**
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Specialists in Corrosion Resisting Coatings and Linings

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industrial news

School for teachers

Refinery planning, design, start-up and operation were the subject matter at a One Day School for Teachers held in Toledo, Ohio, on October 16. Under the joint sponsorship of A.I.Ch.E. and Standard Oil of Ohio, the One Day School consisted of three lectures and a tour of the new integrated refinery of Standard Oil.

Covered under Planning, were studies conducted to provide information required to determine: size, design, crude, location, product mix, process line-up. Design pointed out some of the reasons for selection of the processes used for the Toledo Integrated Unit, basic principles of integration, and flexibility of design standards. Included was a discussion of unique design features. Changes in design concepts caused by operational experiences were included in the startup and operations session.

New 100 short ton per day sulfur recovery plant at the Paulsboro, N.J. refinery of Mobil Oil. The unit has an operating flexibility range of from 21% to 100% capacity. When the high purity sulfur is obtained from processing sour refinery gases, shipment is made in the molten state. The unit was constructed by Badger.

Correction

In the article on page 94 of Chemical Engineering Progress, July, 1959, titled "Corrosion Resistance of Titanium Alloys," the names of the authors were inadvertently omitted. The story should have been credited to M. E. Komp and S. Abkowitz, both of Mallory-Sharon Metals Corp.

For more information, circle No. 99

new..

"Varec" Dynamatic

HIGH ACCURACY AT LOW COST

Power Operated

liquid level

TANK GAUGE

- Accurate to better than 1/16".
- Readings in feet inches and sixteenths.
- Graduations available in metric and decimal.
- No floats, counterweights or spring balances.
- Large, easy to read numbers on dial and counter.

The *Dynamatic* Power Operated Gauge utilizes a force balance system arranged to detect and display liquid level. The measuring device consists of two elements; a force measuring element and a displacer that is a solid plate of any material suitable to the environmental conditions.

Friction–the specific gravity of the product– the load placed on the gauge head to drive accessory controls and remotes–turbulence–none of these have any adverse effect on the accuracy or reliability of the gauge.

The remarkable low cost and the high level of accuracy and sensitivity have been achieved by Varec's uniqueness of design and not by the sacrifice of quality materials and workmanship. ● *Request Bulletin CP-3705* ●

The Vapor-Recovery Systems Company - Compton, Calif.

equipment feature

Design of process heaters

Process heaters are assuming increasing importance in the chemical engineering equipment field. Here are details of design and operation of such heaters.

K. R. WAGNER,
Foster Wheeler Corp, New York.

In general, all process heaters, regardless of their shape, will consist of two separate zones: a radiant zone wherein the major portion of the heat is supplied to the process stream by radiation to tubes located in the combustion chamber; and a convection zone wherein the major portion of the heat is supplied by convection from the products of combustion. The convection zone or bank is usually located in a separate section, or is located behind a shield or shock bank of tubes.

Thermal efficiency

Not too long ago, a thermal efficiency of 72% net was considered high; today, efficiencies of 78-83%, or up to 88% with the use of air preheaters, are common. The efficiency of a heater is largely dependent on the inlet temperature of the feed stock entering the convection section. A temperature approach of 250-300°F between the incoming feed stream and the effluent flue gas is reasonable: more recently, due to the higher cost of fuel and with the use of extended surface, an approach of 100-150°F is considered feasible and economical. For certain applications, such as catalytic reforming, where the inlet temperature to the heater is very high, generally in the order of 900°F, waste heat steam generation is quite often employed to improve the overall thermal efficiency.

Radiant heat transfer rate

Radiant heat absorption rates are a function of the physical size and shape of the heater. In the conventional type of heater where the tubes are located on the walls of the enclosure, the average radiant transfer rate will be limited by the peak point rate to any tube or by peak tube metal temperature considerations. The limiting factor is the tendency of the oil to coke or decompose at the tube wall at the point of highest heat density. The designer must consider the variation in heat density along the length of the tube, from one tube to another, and circumferentially around each tube. He can arrange the heating surface so that the variation in heat density from tube to tube will be less than 5% or as great as 25%.

For any given tube size and spacing, the variation in heat density around the circumference of the tube is fixed. It can be demonstrated that when a tube receives radiation from one side only, the variation in heat density from the average will vary from a maximum of 1.738 to a minimum of 0.606 when the spacing is two tube diameters. For this reason, the designer must carefully consider the average transfer rate in the heater. When average radiant transfer rates of 15,000-17,000 BTU/Hr./Sq. Ft. are specified, the peak rate will be in the order of 26,000-29,000 BTU/Hr./

continued on page 112

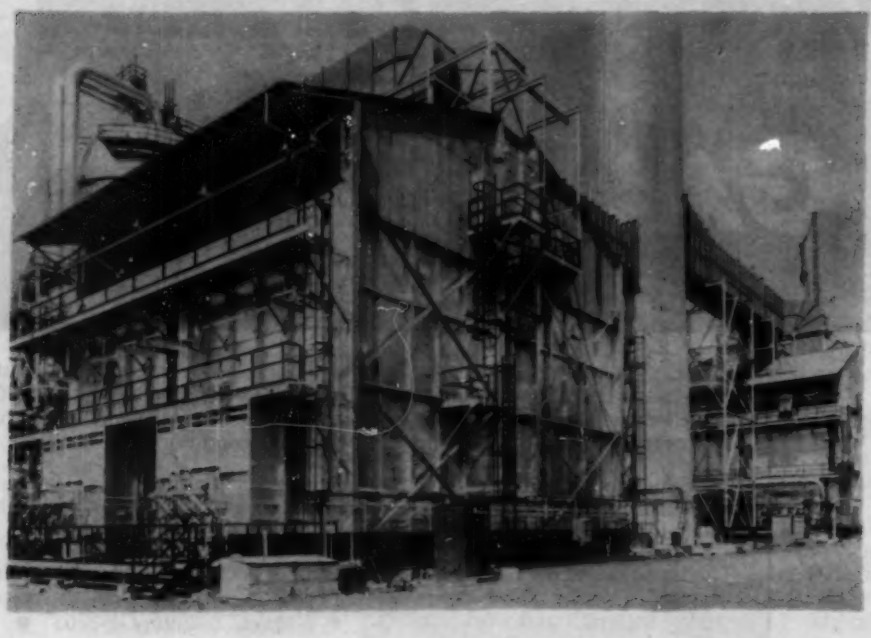

Figure A. Large atmospheric and vacuum heaters for East Coast refinery.

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Stratco Contactors may be designed for almost any degree of mixing short of homogenization. With internal heat transfer surface they provide extremely close control of temperature throughout the entire liquid volume of the contactor. The reacting liquids are maintained in the desired degree of dispersion throughout their residence time, and residence time may be varied to suit the problem.
Stratco Contactors are available in sizes from 300 cc volume laboratory units up to 11000 gallon volume or larger commercial sizes.

• They are adaptable to your process problems . . . large or small

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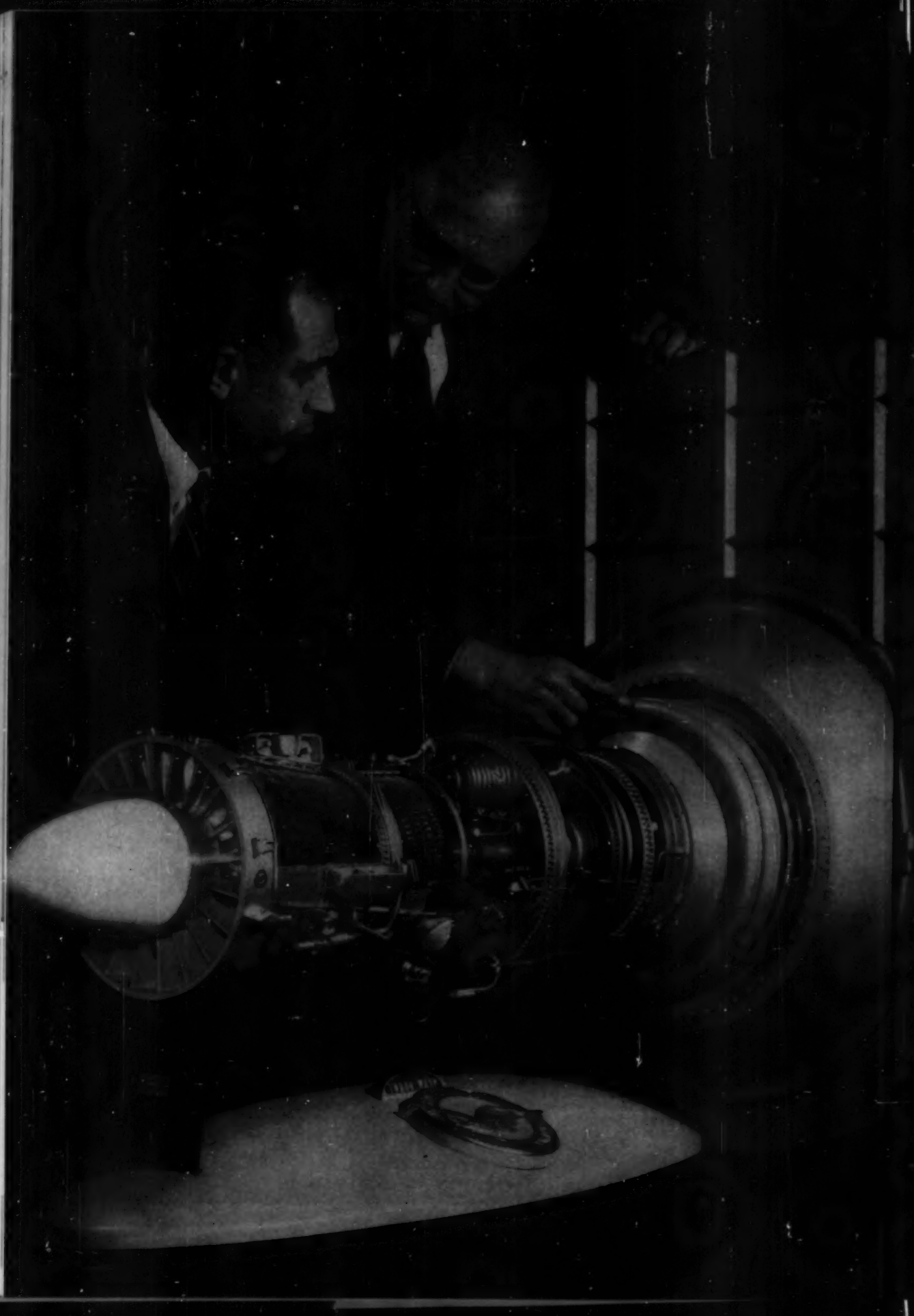

How Cooper-Bessemer is teaming up with Pratt & Whitney Aircraft to develop JET TURBINE POWER for industry

The cutaway model shown is a revolutionary new concept in gas turbines. The generating unit is a new Pratt & Whitney Aircraft jet engine—a modification of the famous J-57 aircraft engine, designed for gas fuel. The companion power unit is a new Cooper-Bessemer power turbine. This combination, now in the advanced experimental stages, represents the hottest development in industrial power in 20 years. It will mean drastic economies in installations of engine-driven compressors, generators and other rotating machinery.

For example, in gas compressor stations, it is expected to reduce total station cost by 50%!

Plans call for this new gas turbine to be available for broad application within 18 months. In the meantime, watch for reports on further developments in this pioneering teamwork by Cooper-Bessemer and Pratt & Whitney Aircraft.

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Quarter-scale model of experimental unit for jets being developed by Cooper-Bessemer and Pratt & Whitney Aircraft. Units should be available for use within 18 months.

For more information, turn to Data Service card, circle No. 119

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Ucon heat-transfer fluids have good viscosity stability and low pour points. These properties permit operation over wide temperature ranges yet eliminate cold weather problems and the need for auxiliary heating equipment.

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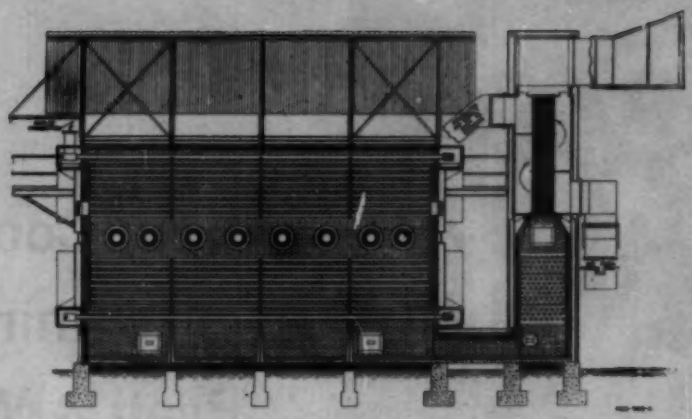


Figure B. Typical arrangement of oil heater with tubular air heater.

Process heaters

from page 108

Sq. Ft. In recent years, a heater design has been developed which results in a lower ratio of peak to average radiant transfer rate. Heaters of this type have tubes located in the center of the enclosure and receive heat from both sides by direct radiation. For this configuration, the variation in heat density from the average around the circumference of the tubes will be 1.150 as a maximum to 0.752 as a minimum when the tube spacing is two tube diameters. These heaters have particular application in reforming and cracking processes, where short residence time and high temperatures are involved.

Convection heat transfer rate

Having selected an overall thermal efficiency and an average radiant heat transfer rate, the designer is more restricted in the design of the convection section. Variables available are arrangement of surface to give a reasonable flue gas mass velocity across the tube bank, and selection of the type of heating surface.

The critical area is that zone which will receive heat both by direct radiation and by convection. It is customary practice to place the tubes located at the entrance to the convection section on wide centers, so that the superimposed convection heat transfer rate will be minimized, thus eliminating hot spots and localized overheating with possible coking.

In recent years, there has been a tendency to use extended surface to reduce the number of tubes and return bends required in the convection section. When extended surface is used, the equivalent bare tube transfer rate may be in the order of 15,000 to 20,000 BTU/Hr., or even higher. This, of course, must be checked for peak film temperatures where the possibility of coking is present.

Tube size

It is important to provide for an adequate fluid mass velocity through the tubes so that the flow will be well in the turbulent range. Certain minimum mass velocities are required for various services to keep the temperature drop across the fluid film to a reasonable value and to avoid skin cracking and coking. To meet this requirement, and at the same time not encounter excessive pressure drop through the coil, it is often necessary to split the flow into a number of parallel streams. It is desirable to locate each stream symmetrically in the combustion chamber so that the heat input to each coil will be essentially the same. One principal advantage of the vertical cylindrical type of heater is the flexibility possible in selecting the number of parallel streams while at the same time maintaining symmetry of heat flow to each of the coils.

At times, it is also necessary to increase the tube size from inlet to outlet to limit the peak bulk temperature below that which will result in coke formation and excessive pressure drop. This is the case of vacuum heaters where it is necessary to handle high percentages of vapor at low pressures.

The tube coil

The tube coil is by far the most important and probably the most expensive item in the heater. Proper

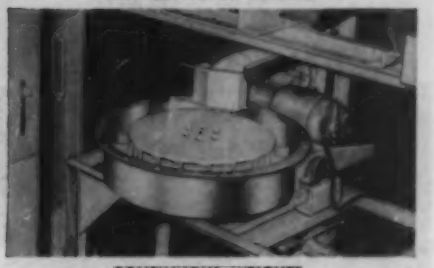
continued on page 116

STEPHENS-ADAMSON

REDLER® Conveyor-Elevator

ZIPPER® BELT CONVEYOR-ELEVATORS

BELT CONVEYOR SYSTEMS



CONTINUOUS WEIGHER

SPEEDS EFFICIENCY...LOWERS COST IN CHEMICAL HANDLING

When you consult a conveyor manufacturer on a particular bulk materials handling problem, you do so because the consultant is a specialist in his phase of the business. But think of the advantages if that consultant were not only the manufacturer of a particular type of conveyor but a specialist in chemical handling systems.

STEPHENS-ADAMSON is just that kind of a consultant. The systems that S-A engineers are regularly designing and installing for the chemical processing industry are not based on a desire to sell a particular type of conveyor system — but the most efficient, profitable answer to the problem at hand. The reason is twofold — S-A's broad knowledge of the field and the fact that S-A makes not one, but several kinds of conveyor systems, some exclusive and patented by the company. Over 20,000 successful installations of the S-A Redler Conveyor-Elevator System alone, point up the breadth of S-A experience. Write today for full information.

MORE S-A EQUIPMENT FOR PROFITABLE CHEMICAL HANDLING

- Box Car Unloaders
- SWIVELOADER® Centrifugal Thrower Unit
- TELLEVEL® Bin Level Controls
- Bucket Elevators
- Ship Unloading Systems
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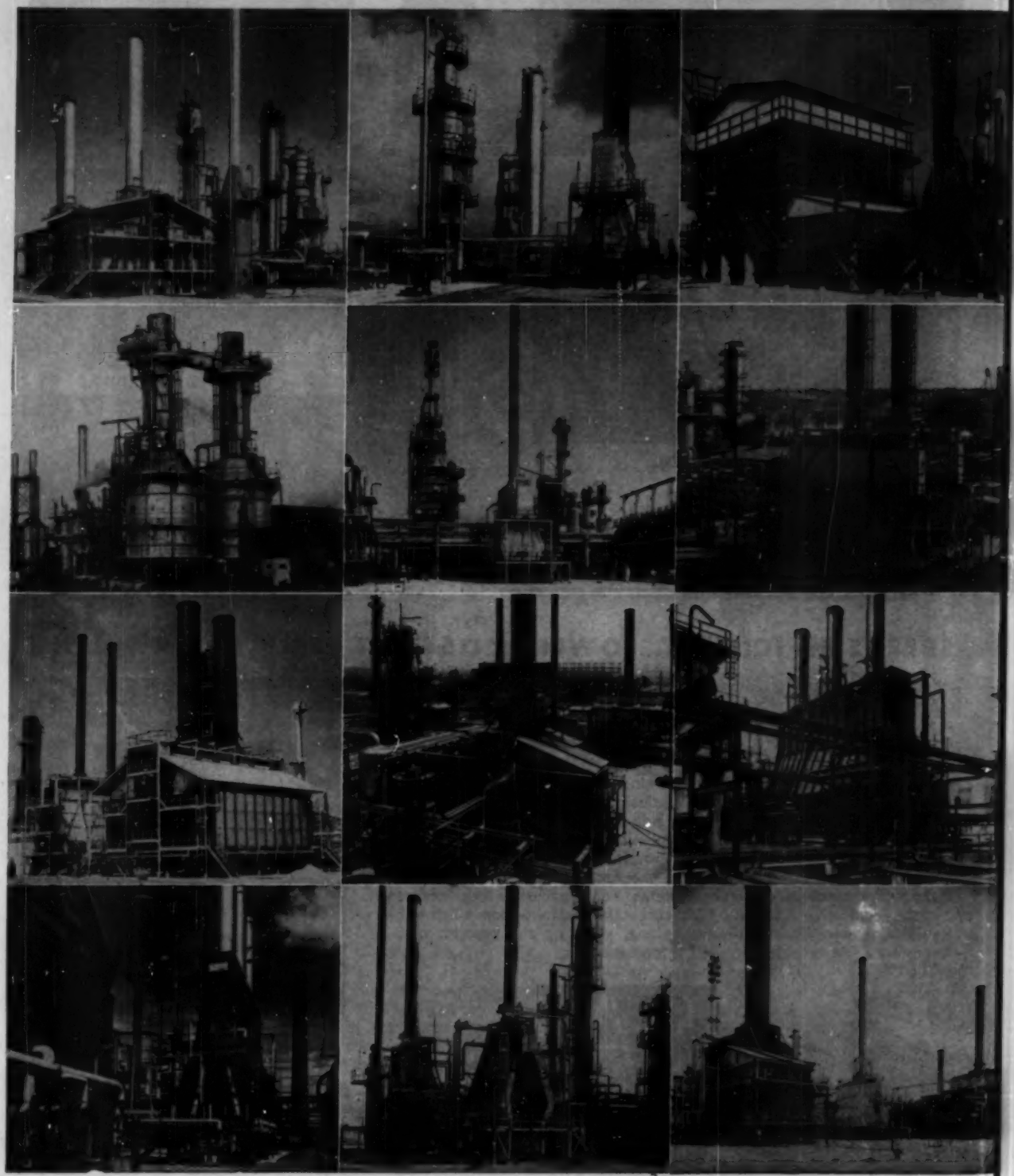

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Furnaces are a major part of the total investment in a petroleum refinery or chemical plant—and vital to its production and income. Variances in operating efficiency or frequent time out for repairs can quickly offset the slight initial savings made with inadequately engineered or "standardized" equipment.

Designing and building furnaces to meet precisely *all* the many specific needs of each individual unit, and thus assure optimum return on investment, has been for over 30 years an integral part of The M. W. Kellogg Company's complete engineering and construction service.

With the recent expansion of this highly specialized furnace division, Kellogg now can offer its unique background in thermodynamics and furnace technology broadly to the process industries as an independent service—backed by the experience and facilities of the entire Kellogg engineering organization.

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A LOT OF CONTROL IN A SMALL SPACE

DAHL
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VALVES

Dahl "Bantam" 2020, 2030 and 2031 series are highly compact, diaphragm-operated on-off valves. Each features the desired ruggedness and high quality of larger valves, and yet, allows appreciable savings in space. All have cast globe bodies for steam, liquid or gas applications.

"Bantam" valves have excellent flow characteristics, low hysteresis and fast response. Use of TEFLON® packings eliminates frequent packing adjustment and greatly reduces maintenance.

MAXIMUM Cv	40.0
LIFT	⅜"
SEAT AREA	up to 3.1 sq. in.
CONNECTIONS	¼" to 2" N.P.T.
PRESSURE RATING	150 psi for steam 300 psi for liquid & gas
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COMPANY, INC
86 TUPELO STREET, BRISTOL, RHODE ISLAND

For more information, circle No. 93

from page 112

evaluation in the selection of tube material must be made for heaters operating with corrosive feed stocks. Since corrosive rates increase rapidly with increase in temperature above the range of 600-650°F, it is sometimes possible, from an economic point of view, to split the coil, using carbon steel tubes at the cold end and 5% chrome or higher alloy tubes at the hot end. In addition to corrosion, the tubes are subject to external oxidation. In the normal tube metal temperature range up to 900-1,000° F, oxidation proceeds slowly enough to permit use of carbon steel tubes in non-corrosive service. However, in

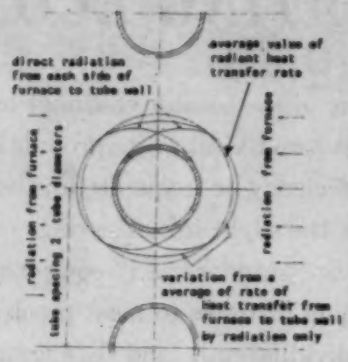

direct radiation from each side of furnace to tube wall
average value of radiant heat transfer rate
radiation from furnace
radiation from furnace
tube spacing 2 tube diameters
variation from a average of rate of heat transfer from furnace to tube wall by radiation only

Figure C-1. Variation of heat transfer around tube fired from both sides.

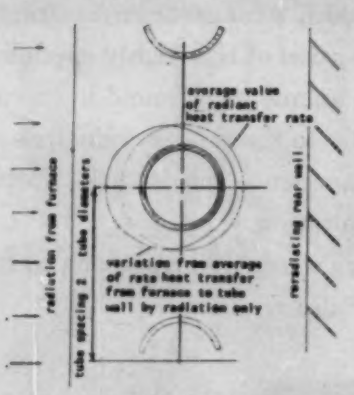

average value of radiant heat transfer rate
radiation from furnace
tube spacing 2 tube diameters
variation from average of rate heat transfer from furnace to tube wall by radiation only
refractory rear wall

Figure C-2. Variation of heat transfer around tube fired from one side.

applications such as high temperature cracking, reforming, steam superheaters, and air heaters, oxidation rate becomes an important consideration.

Tube wall thickness

The important thing to determine first in any tube wall thickness calculation is the tube metal temperature. The allowable stress used in the calculation of the tube wall thickness is a function of the tube metal temperature. In general, the tube wall temperature is obtained by summing up the temperature drop across the oil film, the temperature drop across the coke film, and the temperature drop across the tube wall, and adding these to the bulk fluid oil temperature. Of these, the temperature drop across the fluid film is usually the largest. The most commonly used formula for calculating the inside heat transfer film coefficient is the Sieder and Tate equation. The actual temperature drop across the oil film is then obtained by dividing the peak radiant transfer rate by the inside oil film coefficient. A considerably less conservative design results when the average radiant transfer rate is used. For service where coking is expected, it is also customary to consider a 1/16 in.-thick coke film on the inside of the tubes. A conservative design stress basis is 1% creep in 100,000 hours. Based on normal operation, this could result in a tube life of approximately 10 years. However, operating upsets, flame impingement, oxidation, and corrosion usually reduce the life below this figure.

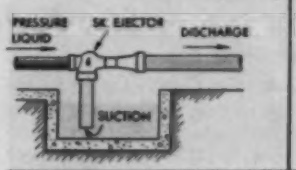
Specification of refractories

Refractories are usually designed for a surface temperature of 1,400°F where protected by tubes, and 1,600° F on unprotected walls. Even in high-temperature heaters, the wall surface temperature will not normally exceed 1,800°F. The wall construction should be designed to result in a maximum outside surface temperature of 200°F, based on still air at 80°F. Several types of refractory construction are available. One is the suspended wall construction consisting of firebrick suitably held in place by tile support castings fastened to structural steel members. Another type is the insulating firebrick construction which may be of the gravity or suspended type. The light-weight insulating firebrick construction has several advantages over the heavy tile construction. There is lower heat storage, thus permitting faster start-up and cooling-off periods. The actual weight is less. Therefore, lighter steel construction is necessary. Because of the low heat capacity, the heater will respond quicker to process changes. The better insulating qualities of the light-weight refractory permit walls of thinner construction with no greater resultant heat loss.

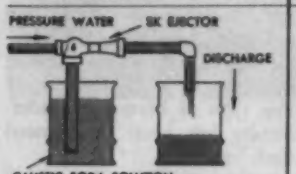
continued on page 118

FOR $50.60 EACH* YOU CAN STOCK EJECTORS THAT WILL PUMP, MIX, EVACUATE, AGITATE

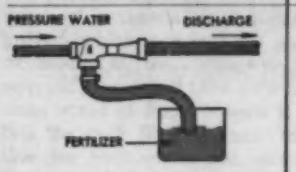
*SK Fig. 264, 2-inch, bronze Liquid Jet Ejector. F.O.B. Cornwells Heights, Pa.



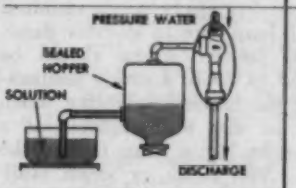
Pumping out a sump



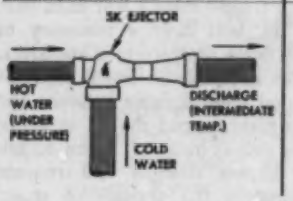
Diluting caustic



Handling slurry



Evacuating air (vacuum lift)



Heating cold water

Want to pump out a sump . . . mix two liquids, or a liquid and a solid . . . handle a slurry . . . prime a pump . . . agitate a solution? Low cost, uncomplicated SK Liquid Jet Ejectors are ideal for *any* of these jobs. That's why thousands of companies (like yours) keep several *always* in stock. Liquid Jet Ejectors utilize the kinetic energy of a pressure liquid to pump, mix and agitate other liquids, handle slurries and fine solids, and evacuate air. They are stocked in cast iron, bronze, 316 stainless steel, PVC, Haveg, and PYREX brand tubing, for quick delivery. The sketches will give you a few ideas on how you might use a stock ejector. For complete details on types, sizes, capacities, write for Bulletin 2M.

For immediate delivery, standard SK Jet Ejectors, Rotameters, and Flow Indicators are stocked in Cornwells Heights (Phila.), Pa., Houston, Texas, and San Francisco, Calif.

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ROTAMETERS & FLOW INDICATORS: Ask for Condensed Bulletin M-1.
VALVES: Ask for Condensed Bulletin V-1.
HEAT TRANSFER APPARATUS: Ask for Condensed Bulletin HT-1.
GEAR PUMPS: Ask for Condensed Bulletin G-1.

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Crystallizers

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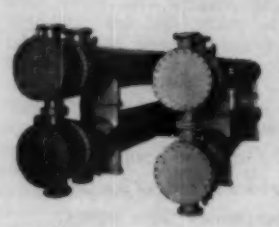

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Pressure Vessels — Agitation Equipment

Lube Oil Consoles

Process Plants — Special Electronic Devices

For more information, turn to Data Service card, circle No. 101

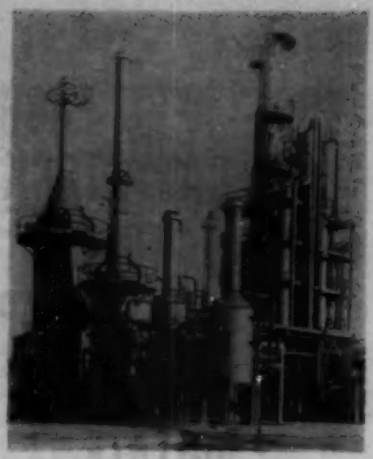


Figure D. Typical vertical cylindrical heaters.

Process heaters

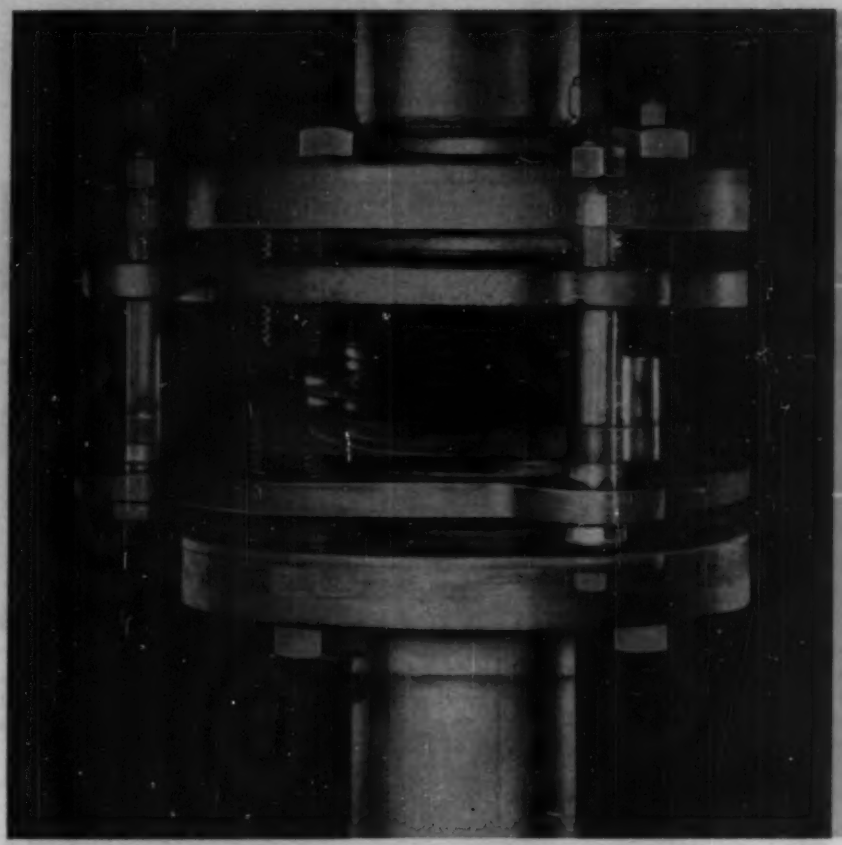
from page 116

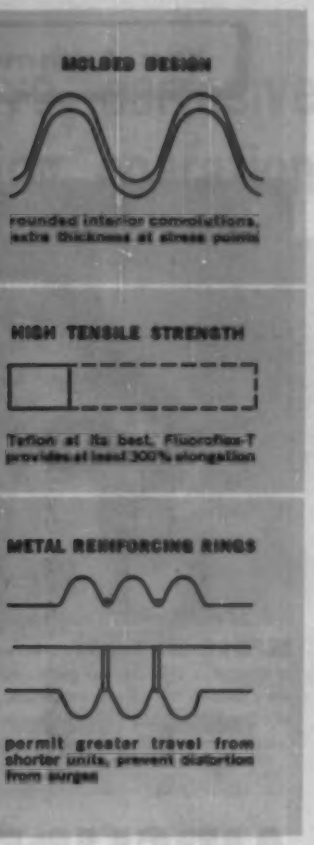
Firing equipment

In recent years, with the introduction of reforming operations, many gaseous fuels now contain considerable quantities of hydrogen. Because of the very rapid flame propagation characteristics of hydrogen, gas burners of the raw gas type are gaining considerable favor. With the use of the premix type of burner, considerable difficulty has been experienced due to flash back.

The burning of fuel oil requires considerably more attention. In many refineries, the fuel is a residue having a high viscosity, and is mixed or blended with light fractions. This type of fuel is most difficult to burn, since the light fractions will flash off and burn while the heavy fuel oil will have a tendency to be poorly atomized and will burn with an unstable flame. A good preheat system should be provided to insure a steady temperature at the burner. Atomizing steam should be dry and available at a temperature higher than that of the fuel oil. Wet steam, or steam available at a temperature lower than that of the oil, will have a tendency to cool the flame and produce sparklers. It is also advisable to use a constant differential control valve between the atomizing steam and the oil to maintain the proper ratio of steam to oil. Proper burner designs will require approximately 0.3 pounds of steam per pound of oil.

Condensed from a paper delivered by K. R. Wagner, Foster Wheeler Corp., New York, at the 14th annual meeting of the three Oklahoma Sections of A.I.Ch.E., April 25, 1959.




MOLDED DESIGN
rounded interior convolutions, extra thickness at stress points
HIGH TENSILE STRENGTH
Teflon at its best, Fluoroflex-T provides at least 300% elongation
METAL REINFORCING RINGS
permit greater travel from shorter units, prevent distortion from surges

2 MILLION CYCLES AND STILL FLEXING!

...proving that this Teflon expansion joint—molded of Fluoroflex-T —outlasts most other materials and constructions

Chemical manufacturer: Tried Fluoroflex®-T joint, found it *still* flexing after *2 million cycles;* previously had averaged 100,000 cycles from machined Teflon® flex joint in pumping application.

Major industrial product company: Displaced one end of a special Fluoroflex-T bellows ¾-inch from its axis, rotated it around axis at 1,000 rpm. After *20 million cycles,* with still no sign of deterioration, test discontinued.

Petrochemical processor: Installed Fluoroflex-T joints to replace joints machined from Teflon. The Fluoroflex-T joints are still in service after nearly a year.

Fluoroflex-T flex and expansion joints perform so much better for three reasons: (1) *The material:* a patented compound of Teflon that combines high density with low crystallinity for optimum strength and flexibility. (2) *The process:* a unique technique for molding uniform convolutions with restraining rings. This gives undamaged grain structure, rounded interior convolutions and increased strength. (3) *The experience:* Resistoflex has been working with fluorocarbon resins since their inception. For fabricating with Teflon, such experience is *vital.* That's why Fluoroflex-T is Teflon at its best.

So, for corrosion-proof flex and expansion joints that give unsurpassed working life, specify Fluoroflex-T. Write for Bulletin B-1A. Dept. 407, RESISTOFLEX CORPORATION, Roseland, N. J. Other Plants: Burbank, Calif.; Dallas, Tex.

®Fluoroflex is a Resistoflex trademark, reg., U. S. pat. off.
®Teflon is DuPont's trademark for TFE fluorocarbon resins.

Complete systems for corrosive service

RESISTOFLEX

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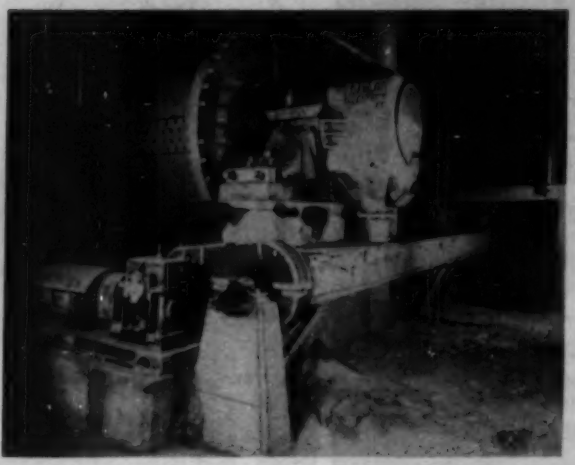
The Arithmetic of Materials Handling

See our exhibit at Chem Show, New York Coliseum November 30-December 4



BEFORE: Dirt, noise and mechanical breakdown were constant problems in this cement plant, where two mechanical conveyors were used to collect raw materials. A 5 h.p. motor driving auxiliary equipment wasted valuable space and power, required frequent maintenance. Spillage clean-up wasted costly man-hours.

AFTER: Clean, simple, quiet. Notice the difference two 8" F-H Airslide® fluidizing conveyors have made. No dangerous moving parts. Nothing to lubricate. Auxiliary equipment and foundations are gone. Power needs are now only ⅓ of previous needs. Fluidizing saves wear and maintenance.

AIRSLIDE® Fluidizing Conveyor

minimizes material loss . . . maintenance . . . moving parts

If you are now handling dry, pulverized materials, the F-H Airslide Fluidizing Conveyor can help you stop noise, and air-pollution, as well as speed flow and reduce maintenance cost.

Simplicity Itself

F-H Airslide conveyors fluidize dry, pulverized materials with low pressure air.

These materials literally flow at high speed, down the inclined conveyor. Power requirements are small.

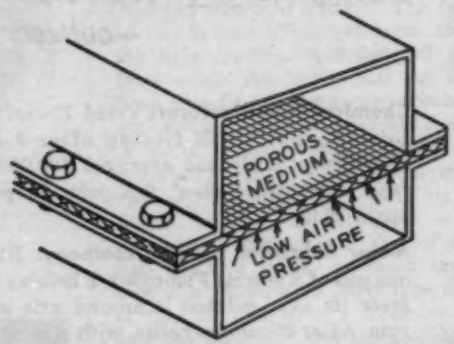
Flexibility, Low Cost

For unlimited applications, Airslide conveyors take up little space, and can be used singly and in combination with other Fuller pneumatic conveying systems. The movement of fluidized material can be around corners, between floors, through walls—nearly any conveying distance.

Better Housekeeping

Can Fuller conveying systems help eliminate your housekeeping problems—cut your maintenance and handling costs? Write today, outlining your problem in handling dry, finely-divided materials. Fuller will gladly make appropriate recommendations.

"Pulverized Materials Flow Like Water!"



FLUIDIZING PRINCIPLE: Porous supporting medium divides conveyor section into two "compartments". Dry material flows down inclined conveyor, fluidized by low-pressure air entering beneath porous medium.

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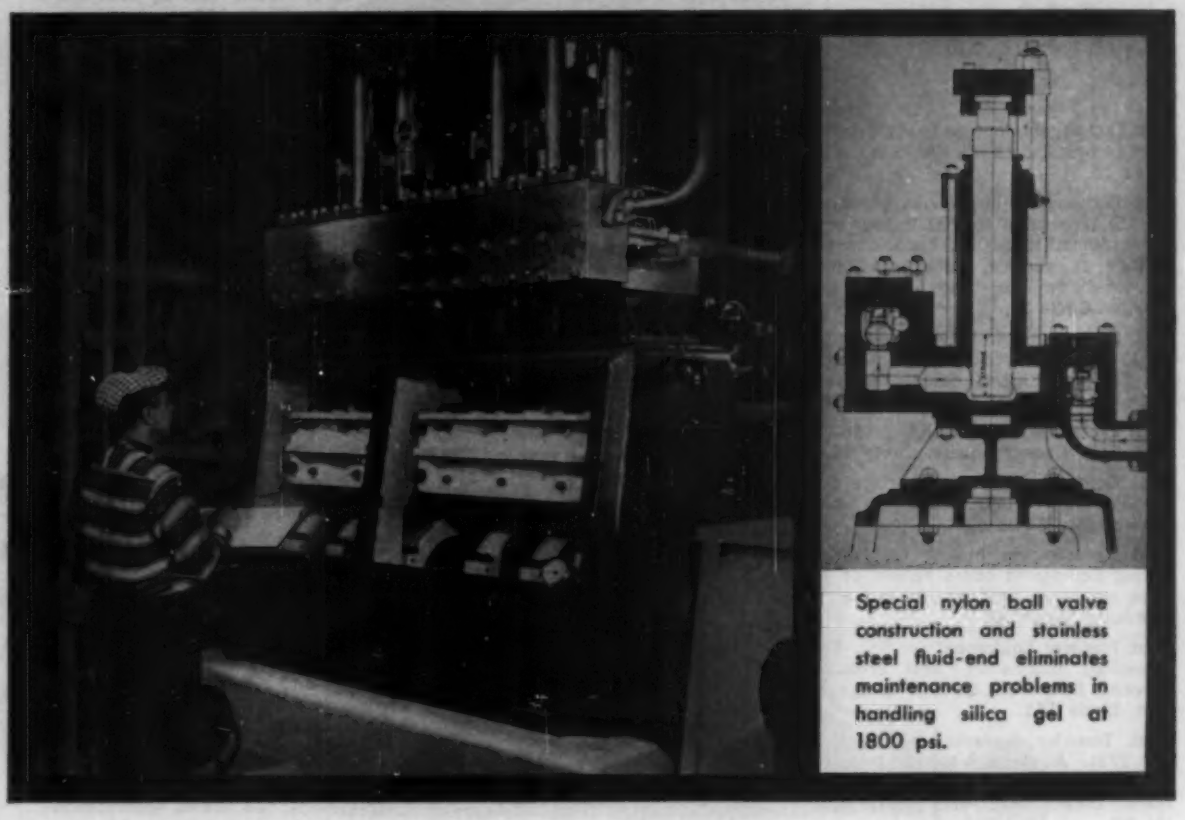
"See Chemical Engineering Catalog for details and specifications".

For more information, turn to Data Service card, circle No 9

The following 2 pages that appear to be missing are reader service cards and have been removed.

AT DAVISON CHEMICAL LTD.

Aldrich pumps tame highly abrasive, corrosive slurry in high pressure spray drying operation



Special nylon ball valve construction and stainless steel fluid-end eliminates maintenance problems in handling silica gel at 1800 psi.

When Davison Chemical Ltd. built its new plant in Valleyfield, Quebec, for the production of petroleum catalysts, a major problem was to find a pump that (1) had the abrasion and corrosion resistance to stand up in a continuous high pressure process without downtime or excessive maintenance and (2) could maintain the steady pumping pressures necessary to control particle size, density and porosity of the spray dried product.

What was done: Davison Chemical engineers called on Aldrich for help and the result was the special valve design shown. After two years of continuous operation, the Aldrich pumps continue to deliver constant pressure without major overhaul. The General Manager of the plant reports: "We are quite pleased with the performance of these pumps."

How Aldrich can help you: Solving special pumping problems for the chemical industry is the most important work we do. We would welcome the opportunity to discuss your specific problems . . . no matter what the liquid or slurry, or how high the pressures. Standard Aldrich Pumps range from 25 to 2500 hp. Pressures to 30,000 psi. See our insert in Chemical Engineering Catalog for condensed data. Aldrich Pump Company, 20 Gordon Street, Allentown, Pennsylvania.

the toughest pumping problems go to ALDRICH

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CEP'S DATA SERVICE—Subject guide to advertised products and services

CIRCLE CORRESPONDING NUMBERS ON DATA SERVICE CARD

EQUIPMENT *from page 122*

Heat Exchangers, fin-type (p. 92). Complete technical data from Aerofin Corp. **Circle 16.**

Heat Exchangers, impervious graphite (p. 15). Pressures to 200 lb./sq. in., temperatures to 340°F, capacities to 470 sq. ft. surface. Data from Falls Industries on the "Cross-Bore" exchanger. **Circle 53.**

Heat Exchangers, impervious graphite (p. 177). Bulletin 156 from Heil Process Equipment gives details of shell and tube, immersion types. **Circle 124.**

Heat Ex hangers, panel coil (p. 182). Data from Dean Products. **Circle 94.**

Heat Exchangers, scraped surface (p. 29). Technical details from Henry Vogt Machine Co. **Circle 42.**

Heat Transfer, in mixing (p. OBC). Mixing Equipment offers reprint of 4-page article on heat transfer research in mixing. **Circle 33.**

Heat Transfer Equipment (p. 95). Engineering, fabrication, and erection services. Data from Chicago Bridge & Iron. **Circle 141.**

Heat Transfer Systems, liquid-phase (p. 173). All-electric Merrill Process System can use oil, Aroclor, or Dowtherm. Details from Parks-Cramer. **Circle 80.**

Heating Systems, transfer oils (p. 146). Data from Whitlock Mfg. on standard package units. **Circle 55.**

Heating Units (p. 150). Bulletin 158 from Hevi-Duty Electric Co. **Circle 65.**

Joints, ball, flexible (p. 134). Catalog 215B and Bulletin 31 from Barco Mfg. **Circle 56.**

Joints, expansion, Teflon (p. 119). Bulletin B-1A from Resistoflex gives technical info on "Fluoroflex-T" expansion joints. **Circle 139.**

Kilns (p. IFC). Bulletin 118 from C. O. Bartlett & Snow gives full technical details of continuous and batch processing kilns. **Circle 2.**

Materials Handling Equipment (p. 113). Catalog 358 from Stephens-Adamson Mfg. **Circle 49.**

Materials Handling Equipment, pneumatic (p. 120). Details from Fuller. **Circle 9.**

Materials Handling Systems, pneumatic (p. 179). Details in Bulletins 118 and 208 from Sprout-Waldron. **Circle 39.**

Mills, grinding, fluid energy (p. 105). Technical data from Fluid Energy Processing & Equipment on the "Jet-O-Mizer" mill. **Circle 29.**

Mills, grinding, impact (p. 150). Technical data from Entoleter, Div. of Safety Industries. **Circle 32.**

Mixers (p. 99). Six standard models, 1 to 200 hp. Catalog A-19 from Philadelphia Gear. **Circle 106.**

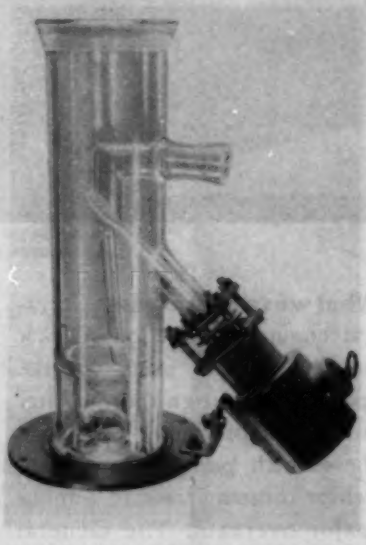
Mixers, mass and paste (p. 156). In capacities from 3 to 300 gallons. Info from Paul O. Abbe. **Circle 92.**

Mixer, planetary (p. 154). Technical and price info from J. M. Lehmann. **Circle 78.**

Mixers, turbine-type (p. 89). Technical Bulletin from Process Equipment Div., General American Transportation. **Circle 10-1.**

Nozzles, spray (p. 132). Complete Catalog 24 from Spraying Systems. **Circle 138.**

DEVELOPMENT OF THE MONTH



AUTOMATIC REFLUX SPLITTER

(Circle 602 on Data Post Card)

Pyrex and Teflon construction makes this unit completely corrosion resistant to all liquids except hydrofluoric acid and hot concentrated caustics.

The "Chem Flow" splitter is electrically operated by a solenoid and timer. The elimination of valves, product line and reflux line rotometers leads to economies in process pipe layout. The precision timer has an adjustable ratio of 1:1 to 1:20. The splitters are made for pressures up to 50 lb./sq. in., temperatures to 450°F. For complete details from Chem Flow Corp., Circle 602 on Data Post Card.

Nozzles, spray (p. 181). Comprehensive Spray Nozzle Catalog 5600 from Binks Mfg. **Circle 137.**

Packers, vibrating (p. 5). For boxes, cans, cartons, kegs, drums, barrels, up to 750 lbs. Bulletin 401 from B. F. Gump. **Circle 46.**

Packing, tower, carbon (p. 129). Intalox saddles now available from National Carbon. Technical details. **Circle 104-2**

Pall Rings, metal (p. 38). In ⅝, 1, 1½, and 2 in. sizes in carbon steel, stainless, nickel, Monel, Inconel, titanium, copper-aluminum. U.S. Stoneware. **Circle 79.**

Piping, plastic (p. 102). High-impact, rubber-plastic, ½ to 6 in. Bulletin 80A from American Hard Rubber. **Circle 126-3.**

Piping, PVC (p. 102). Schedules 40, 80, & 120, ½ to 4 in. Bulletin CE-56 from American Hard Rubber. **Circle 126-4.**

Preheaters, air (p. 151). Case history of Ljungstrom air preheater application offered by Air Preheater. **Circle 1.**

Processor, thin-film (p. 173). Info from Kontro on "Ajust-O-Film" thin-film processing units with blade-clearance control. **Circle 116.**

Pumps, controlled-volume (p. 36). Bulletin 440 from Lapp Insulator gives applications, flow charts, specifications, special leakage chart. **Circle 14.**

Pumps, corrosion-resistant (p. 102). Hard rubber casing and impeller, Hastelloy C shaft, 80 gal./min. Bulletin CE-55 from American Hard Rubber. **Circle 126-1.**

Pumps, corrosion-resistant (p. 165). Bulletin CT-859 from Eco Engineering. **Circle 77.**

Pumps, gear, steam-jacketed (p. 175). Bulletin 17-A from Schutte and Koerting. **Circle 98.**

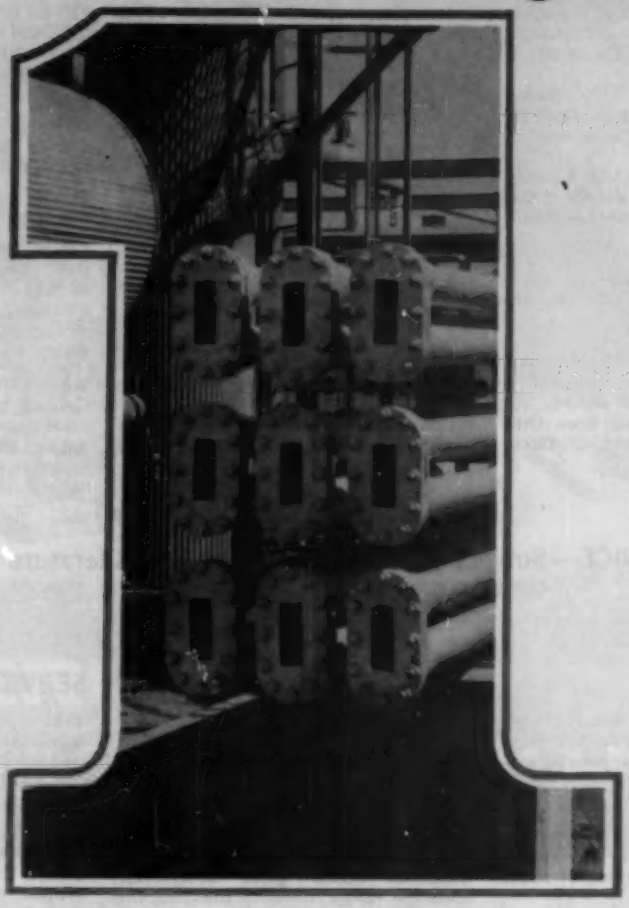
Pumps, glassed (p. 143). Bulletin 725.2 from Goulds Pumps gives complete technical details. **Circle 12.**

Pumps, impervious graphite (p. 129). Now available with choice of mechanical seal. Info from National Carbon. **Circle 104-1.**

Pumps, leakproof (p. 147). Composite Curve from Chempump shows models and sizes available. **Circle 4.**

continued on page 126

The Optimum Standardization on Heat Exchangers is...



AND IT'S ALREADY HERE!

The optimum on standardization of heat exchangers has already been reached. It is one. It is Brown Fintube.

The same basic modular Brown Heat Exchanger can be used for all services for pressures up to 600 p.s.i. and temperatures up to 700° F. By properly combining these modular units into sections they will meet any duty, or capacity requirement. Furthermore, they are altered for any new use simply and quickly by the addition or subtraction of units.

Analysts report that millions of dollars can be saved *if* industry would standardize on heat exchangers. Brown users are *already* saving millions. By using only one basic unit, these companies completely eliminate obsolescence, save engineering time, tremendously reduce parts and standby stores, and simplify maintenance.

If you want the benefits of standardization, contact Brown Fintube. Learn how other plants are already obtaining dynamic operational savings with one basic, standardized unit!

HEAT EXCHANGE SURFACE
BROWN FINTUBE
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BROWN FINTUBE COMPANY

318 HURON STREET, ELYRIA, OHIO • TELEPHONE: FAIRFAX 3-3291

For more information, turn to Data Service card, circle No. 122

CEP'S DATA SERVICE—Subject guide to advertised products and services

CIRCLE CORRESPONDING NUMBERS ON DATA SERVICE CARD

EQUIPMENT *from page 124*

Pumps, process (p. 123). Standard models from 25 to 2,500 hp. Technical data from Aldrich Pump. **Circle 97.**

Pumps, turbine-type (p. 176). Single or two-stage horizontal design. Bulletin 100 from Roy E. Roth. **Circle 69.**

Recorder-Controllers (p. 155). Bulletin 20-10 from Foxboro gives details of the "Dynalog" electronic recorder-controller. **Circle 8.**

Refrigeration Unit, jet-vacuum (p. 141). Details from Croll-Reynolds on the "Chill-Vactor." **Circle 31.**

Separators, entrainment (p. 4). Improve performance of distillation equipment, vacuum towers, knock-out drums, absorbers, scrubbers. Details from Otto H. York on the York "Demister." **Circle 115.**

Tanks, wood, plastic-lined (p. 181). Data from Wendnagel on "Polycel" tanks. **Circle 22.**

Tester, iron (p. 179). Complete with color standards covering the 0-10 ppm range. Data from W. A. Taylor. **Circle 20-2.**

Thermocouple Wire (p. 138). Bulletin 1200-4 from Claud S. Gordon gives technical details, ordering data, prices. **Circle 23.**

Tubes, heat exchanger (p. 6-7). Data from Republic Steel on "Farrowtested" heat exchanger tubes in carbon and stainless steel. **Circle 61.**

Tubes, heat exchanger (p. 19-22). Bulletin from Bridgeport Brass gives corrosion data for tubes in aluminum, brass, copper, special metals. **Circle 130.**

Valves, control, small (p. 116). Catalog B-1 from George W. Dahl on "Bantam" on-off and throttling control valves. **Circle 93.**

Valves, diaphragm (p. 102). Rubber or plastic-lined cast iron, or solid plastic bodies. Data from American Hard Rubber. **Circle 126-2.**

Valves, high-alloy (p. 159). Technical info from Cooper Alloy. **Circle 59.**

Valves, high pressure (p. 9). New "Flo-Ball" design for pressures to 3,000 lb./sq. in. said to have 100% flow efficiency, more than double the flow of needle valves. Hydromatics, Inc. **Circle 13.**

Water Treating Equipment (p. 175). Catalog from Hungerford & Terry describes complete plants for demineralization, dealkalizing, clarification, silica removal, water softening. **Circle 109.**

CEP'S DATA SERVICE—Subject guide to free technical literature

CIRCLE CORRESPONDING NUMBERS ON DATA SERVICE CARD

EQUIPMENT

301 Bulk Handling Equipment. Bulletin from Fluidizer Co. describes componets and completely engineered systems.

302 Cells, chlorination. Bulletin from Diamond Alkali describes use of new oxidation potential cells to control chlorine reaction in bleaching of paper pulp.

303 Centrifugals, batch. Bulletin TC-14-56 from Tolhurst Centrifugals Div., American Machine and Metals, describes its newly-developed "Batch-Master."

304 Compressors, centrifugal. Single and two-stage designs, capacities from 800 to 8,000 cu. ft./min., pressures to 1,000 lb./sq. in. abs. Bulletin P-12 from Elliott.

305 Compressors, heavy-duty. New Bulletin 160 from Clark Bros. gives details of heavy-duty, balanced/opposed compressors for chemical and petrochemical industry. Capacities from 200 to 8,000 bhp.

306 Computers, analog, portable. Bulletin AC934 describes the PACE TR-10, completely transistorized, portable analog computer. Electronic Associates.

307 Computer, general purpose. Bulletin from Bendix details use of its G-15 computer for on-line data processing and control systems.

continued on page 128

MATERIALS

358 Acrylic Esters, monomeric. New, 18-page Booklet from Rohm & Haas offers data on methods for both redox and reflux emulsion polymerization. Also chemical and physical properties, applications.

359 Adhesives. Reference Chart from Benjamin Foster gives description, coverage range, bonding time, service temperature limits, flash point, flame spread index, solvent for clean up, average non-volatile.

360 Aliphatics. Bulletin from Armour Industrial Chemical lists specifications, chemical composition of long and short chain saturated fatty acids, oleic, and unsaturated fatty acids. Typical applications.

361 1, 2 Butylene Oxide. Bulletin from Dow Chemical discusses actual and potential uses as stabilizers, solvents, petroleum additives, plasticizers, lubricants, surface-active agents, flotation agents, textile chemicals, plastics, catalysts.

362 Carbon Monoxide. Physical constant, typical analyses in new Bulletin from Matheson.

363 Corrosion Inhibitor. Data from O'Brien Industries on O'B'Hibit-L 32, new liquid inhibitor recommended for service with hydrochloric acid.

364 1, 4-Cyclohexanedimethanol. Technical info from Eastman Chemical

continued on page 128

SERVICES

378 Computer Analysis, piping systems. Brochure from General Dynamics, Electric Boat Div., describes services offered for analysis of thermal expansion, hanger loads, dead-weight stresses, vibration, natural frequency.

379 Design and Construction, wax plants. Brochure from Badger Mfg. describes Atlantic Refining's new MEK Wax Plant in Philadelphia. Flow chart, process description, engineering and construction details.

380 Fabrication, process equipment. New booklet from Pressure Products Industries gives details of valves, fittings, reactors, agitated vessels, pumps, compressors for pressures to 100,000 lb./sq. in.

381 Fabrication, process equipment. Bulletin CE-59 from Baker Perkins details mixers, kneaders, centrifugals, dryers.

382 Fabrication, process equipment. Bulletin from B-I-F Industries covers meters, instrumentation, feeders, control systems, other process equipment.

383 Fabrication, process equipment. General Product File from Goslin-Birmingham describes filters, evaporators, many other types of chemical processing equipment.

384 Fabrication, process equipment. New Bulletin from General American Transportation covers services and products for the process industries.

continued on page 128

EXPERIENCE

is always on stream *with* AIR LIQUIDE

If you're planning to build a new plant — to extend — or to rebuild . . . tap this rich stream of low-temperature experience! If it's a question of gas separation or recovery, Air Liquide has the efficient, economical, proven answer.

The Air Liquide stream of experience has been flowing around the world for over half a century. Gaining year by year broader and accurate know-how, it has produced hundreds of low-temperature gas separation plants all over the globe.

Whether you need a plant from an existing design or one especially designed for your particular requirements, Air Liquide can supply it. From the initial technical consultations, design work, manufacturing of plant and equipment, to the expert erection and start-up supervision, our widely experienced Research, Design, and Project teams smoothly coordinate with yours.

We shall be pleased to consult with you in the application of Air Liquide processes and equipment to your particular needs. Write or call us at 405 Lexington Ave., New York 17, N. Y. Telephone: YUkon 6-6544.

AIR LIQUIDE HAVE DESIGNED AND BUILT THE FOLLOWING TYPES OF PLANTS

- Air Separation — oxygen, nitrogen, etc.
- Tonnage Oxygen and Nitrogen (Gas and Liquid)
- Rare Gases Recovery
- CO_2 Purification
- Methane Purification
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- Coke-Oven Gas Separation
- Refinery Gas Separation
- Hydrogen Liquefaction
- Helium Recovery
- Pure CO_2 Production
- Heavy Water for Atomic Reactors

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1111 Beaver Hall Hill,
Montreal, Quebec,
Telephone: UNiversity 6-4781

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AIR LIQUIDE
ENGINEERING & CONSTRUCTION DIVISION
OLDEST IN EXPERIENCE — NEWEST IN DESIGN

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For more information, turn to Data Service card, circle No. 117

CEP'S DATA SERVICE—Subject guide to free technical literature

CIRCLE CORRESPONDING NUMBERS ON DATA SERVICE CARD

EQUIPMENT *from page 126*

308 Control Equipment, electronic. "Functional Guide to Autonic Control Equipment," offered by Swartwout. Contains large chart of components arranged functionally.

309 Control System, visual. Graphic Systems offers kit containing material for planning a visual control system. New 24-page booklet, "Graphic Visual Control," serves as manual and catalog.

310 Conveyors, vibrating. New 4-page Catalog Section on mechanical vibrating conveyors from Syntron. Descriptions, technical data, specifications on 7 standard models.

311 Cut-off Machines. Specially designed for cutting heat exchanger tube bundles. Bulletin SM-658 from Wells Mfg.

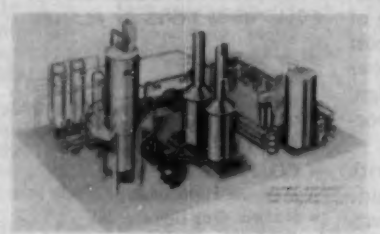
312 Data Processing System. New "Multiplexer 1010" provides automatic communication of programs and computer results between central computer and up to eight remote locations, eliminates scheduling problems. Details from Vitro Laboratories.

314 Dip Pipes, chemically-inert. Designed to withstand severe agitation and thermal shock at temperatures to 500°F. Data from Resistoflex.

315 Dust Collectors, mechanical. Bulletin 300 from Research-Cottrell gives detailed drawings, application diagrams on new involute design.

316 Dust Collectors, wet-type. Bulletin from National Dust Collector gives dimensions, specifications, capacities on four models, capacities from 1,000 to 40,000 cu. ft./min.

DEVELOPMENT OF THE MONTH



PACKAGES HYDROGEN GENERATION PLANTS

(Circle 603 on Data Post Card)

Complete packaged plants are offered by Selas Corp. of America for producing up to 10,000 cubic feet per hour of high-purity hydrogen. Capacities range from 1,000 to 10,000 cubic feet per hour, hydrogen purity is up to 99.995%.

The unit is fully automated for continuous operation without supervision, and is instrumented for self-protection of major equipment. Product quality is constantly monitored.

For complete technical details, Circle 603 on Data Post Card.

317 Equipment, plastic. New, 27-page Bulletin P-11 from Haveg Industries gives specifications of variety of process equipment in corrosion-resistant, reinforced plastics.

318 Fans, industrial. Bulletin L-5 from Lehigh Fan & Blower Div., Fuller Co., gives complete rating tables, air volumes, rev./min., horsepower.

319 Filters, high-pressure. For pressures to 1,000 lb./sq. in., temperatures to 275°F. Data from Purolator Products on new P-192 series.

320 Filters, horizontal-leaf. New type HL, made by Bowser, Process Filters Div., permits one-man cleaning in 4 to 15 minutes. Technical details.

321 Filters, rotary vacuum. Bulletin from Peterson Filters and Engineering describes disc and drum types.

322 Filter Cartridges, felt. Technical info from American Felt on new precision liquid filter cartridge.

323 Flowmeters. From small purge meters to laboratory rotameters and calibrators. Bulletin from Matheson.

324 Flowmeter, mass, "Gyro-Integrating." Bulletin GEA-6925 from General Electric gives theory, operation details, ranges, specifications, dimensions, cutaway drawings.

325 Furnace, solar. Creates temperatures to 6,741°F. in seconds with heat flux densities up to 365 calories/sq. cm./sec. Low cost. Details from Thermal Dynamic Products Div., Waltham Precision Instrument.

326 Gauge, liquid-level, power-driven. Details from Vapor Recovery Systems on its newly-introduced "Dynamatic." For pressures to 50 lb./sq. in.

327 Heat Exchangers, impervious graphite. Technical Bulletin from Falls Industries.

328 Heat Exchangers, fin-type. New Bulletin 11R describes "Radiafin" exchangers for air and gases. Schutte and Koerting.

continued on page 130

MATERIALS *from page 126*

Products on use in preparation of polyester films and urethane elastomers. Sample quantities also available.

365 Ethylene Oxide. Antara Chemical (General Aniline & Film) offers 48-page technical manual with physical and chemical properties, specifications, analytical procedures, industrial uses.

366 Fatty Acids. New 32-page Booklet from Armour Industrial Chemical describes preparation, characteristics, and applications of 30 fatty acids. Data on specifications, sources, composition, synthesis.

367 Filterald, carbon-based. Brochure from Great Lakes Carbon on "Nerofil" gives properties, flowrates, filter cake density, cake porosity, particle size, caustic solubility.

368 Fluids, engineering. Monsanto offers summary of physical properties of 20 selected functional fluids, including coolants, heat-transfer fluids.

369 Heat Transfer Cements. Engineering Data Book from Thermon Mfg. gives engineering data and calculations, estimating and installation data. Many tables and charts.

370 Heat Transfer Oil. Data sheet from Sun Oil gives physical and thermal properties of Sun 21 Heat Transfer Oil, designed for use in closed circulating systems under temperatures up to 600°F.

371 Packings, self-lubricated. Catalog from Greene, Tweed includes quick calculator tables on weights and lengths, simple ordering instructions.

372 Phthalates, ditridecyl and didecyl. Technical Bulletin from Enjay on "Ditridecyl and Didecyl Phthalates in High Temperature Vinyl Insulation."

373 Polypropylene Film. Technical Data Bulletin gives properties, application data. AviSun Corp.

374 Silicone Fluids. Design File from Union Carbide discusses industrial applications, including effects of silicone fluids on elastomers.

375 Titanates. Data from Du Pont on new series of organic titanium compounds, info on use in manufacture of adhesives, resins, water repellents, other chemical products.

376 Titanium. Technical Brochure from Titanium Metals titled "Titanium Metals Handbook for the Chemical Processor," covers titanium's behavior in about 200 corrosion environments.

377 Trichlorethylene. New 36-page Booklet from Hooker Chemical titled "Nialk (R) Trichlorethylene for Vapor Degreasing and Other Uses." Basic cleaning cycles, physical properties, many charts and graphs.

SERVICES *from page 126*

385 Fabrication, process equipment. Catalog 386 from Blaw-Knox details evaporators, drum, rotary, spray, and pan dryers, flakers and coolers, autoclaves.

386 Heat Transfer Chart. Dean Thermo-Panel Coil Div., Dean Products, offers handy chart for determining logarithmic mean temperature difference.

387 Technical Data Books. Catalog from Lefax Publishers covers technical data books in every field of engineering.

News from
National Carbon Company
Division of Union Carbide Corporation · 30 East 42nd Street, New York 17, N. Y.
Sales Offices: Atlanta, Chicago, Dallas, Kansas City, Los Angeles, New York, Pittsburgh, San Francisco. IN CANADA: Union Carbide Canada Limited, Toronto

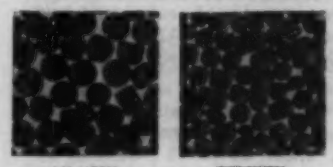
National Carbon representatives expand your engineering force

J. M. BROWN
SALES ENGINEER

After graduating from Purdue University with a B.S. in Chemical Engineering, Brown spent five years in the Cleveland Sales Engineering Department developing new products, equipment design, and performing field installation and maintenance work.

For the past five years, Jim has been working with the chemical industry as a field sales engineer on the application and use of carbon, graphite and "Karbate" impervious graphite products.

New Size Activated Carbon Pellets Available for Catalyst Support

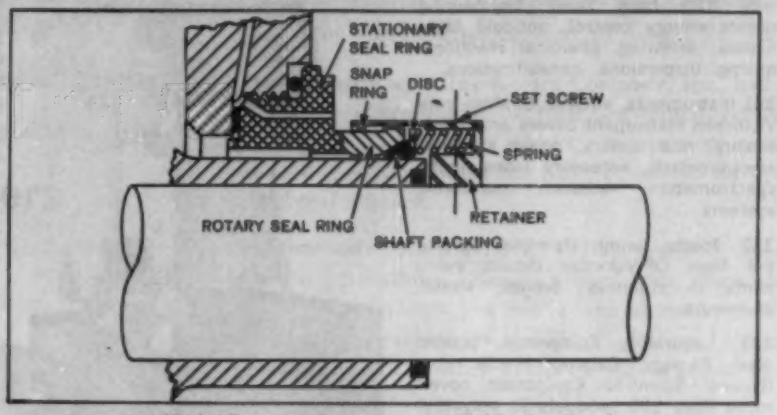


4/6 MESH 6/8 MESH

A *new "Columbia"* activated carbon grade CXC, which has been designated as a catalyst support, is now produced in smaller 6/8 mesh pellets.

The new size pellets have all the properties associated with the original 4/6 mesh size such as high activity, strong and uniform shape, high metal salt pickup, and low active ash. *For details, contact National Carbon Company, 1300 Lakeside Avenue, Cleveland 14, Ohio.*

"Karbate" Pumps with choice of Mechanical Seals assist Seal Standardization



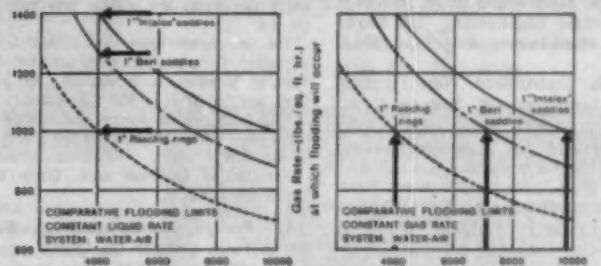
"Karbate" pump seal arrangement with "John Crane" seal

"Karbate" impervious graphite pumps Type C Model CA are available with either NATIONAL CARBON or "John Crane" mechanical seals. The "John Crane" seal arrangement is offered to partially meet the trend within chemical plants to standardize on one type of mechanical seal for rotary equipment.

NATIONAL CARBON's design which has proved satisfactory for many years is standard equipment on Model CA pumps. "John Crane" seals will be supplied as optional equipment.

"John Crane" seals can be installed on any "Karbate" impervious graphite pump Type C Model CA now in service by simply replacing the standard stationary and rotary seal components.

Carbon "Intalox" Saddles provide highest Efficiency and unmatched Corrosion Resistance



Carbon "Intalox" saddles, developed jointly by National Carbon Company and U.S. Stoneware Company, combine the operating efficiencies of the "Intalox" design with the almost universal corrosion resistance feature of carbon. These saddles can be used in stripping, absorbing, and scrubbing applications where hydrofluoric acid, hot alkalis, phosphoric acid, mixtures of hydrofluoric-sulfuric and hydrofluoric-phosphoric acids are present. Carbon saddles withstand abrupt temperature changes without danger of cracking or spalling.

The above graphs show the higher efficiency of "Intalox" saddles as compared to Raschig rings and Berl saddles. The availability of carbon saddles permits the designing of smaller scrubbing, stripping and absorbing towers for highly corrosive applications. Also, capacity of existing towers can be increased by using carbon "Intalox" saddle packing. *For details, contact National Carbon Company, P. O. Box 6087, Cleveland 1, Ohio.*

NATIONAL TRADE-MARK

"National", "Columbia", "N" and Shield Device, "Karbate" and "Union Carbide" are registered trademarks of Union Carbide Corporation

UNION CARBIDE

CEP'S DATA SERVICE—Subject guide to free technical literature

CIRCLE CORRESPONDING NUMBERS ON DATA SERVICE CARD

EQUIPMENT *from page 128*

329 Heating Coils, pipe & fin types. New 48-page Engineering Data Book from Rempe, for the designer of heat transfer equipment. Many charts and tables.

330 Homogenizers, utirasonic. Bulletin 259 from Sonic Engineering covers energy control, hot-cold techniques, defibring, chemical reactions, mixing, dispersions, emulsifications.

331 Instruments, nuclear. Bulletin from Victoreen Instrument covers amplifiers, scalers, rate meters, power supplies, electrometers, accessory instruments, spectrometers, radiation monitoring systems.

332 Joints, swing, stainless. Catalog F-8 from OPW-Jordan details swing joints in stainless, bronze, Monel, aluminum.

333 Laboratory Equipment, plastic. New 24-page Catalog H-459 from General Scientific Equipment covers more than 100 products in polyethylene, polypropylene, polyurethane, polyvinyl.

334 Mills, ball, vibrating. Schutz-O'-Neill offer new line of German-made vibrating ball mills which pulverize, micronize, mix to critical standards. Technical data.

335 Mixers, batch. Models for laboratory or high volume production. Bulletin from Daffin Mfg. gives capacities, horsepower, dimensions.

336 Mixers, right-angle drive. Bulletin from Stockdale Engineering, US Mixer Div., gives dimensions, selection table.

337 Panels, instrument. New 16-page Brochure from Panellit Service Corp. describes complete installation thru start-up service for automation and instrumentation systems.

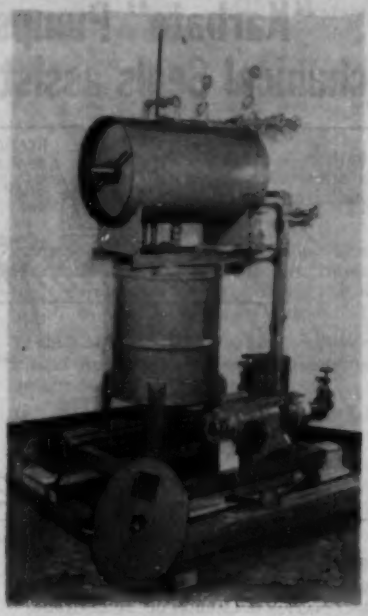
338 Platinum Products. New 20-page platinum products catalog from J. Bishop & Co. includes chemicals, recovery and refining facilities. Conversion tables.

339 Pumps, canned. New Technical Bulletin from Chempump titled "Organic Heat-Transfer Fluids," describes role of canned pumps in handling heat transfer fluids.

340 Pumps, gear. Bulletin from Schutte and Koerting describes applications, construction details, operation, lists types available.

341 Pumps, gear, nickel. Eco Engineering offers technical data on its "Gearchem" pumps, now available in electrolytically pure nickel or caustic service.

DEVELOPMENT OF THE MONTH



LOW COST EXPERIMENTAL FILTER

(Circle 601 on Data Post Card)

A small pressure leaf filter of simplified design is available from Hercules Filter. It is made in capacities ranging from ten to thirty square feet. The unit consists of a flat-ended tank with a fixed center discharge pipe on which the leaves are placed. One bolt fastens the lid.

The ten square footer has a shell length of 12 inches. Complete with filter and full complement of 5 leaves, it is available for $510 in steel, and for $790 in 304 stainless.

The thirty square footer has a shell length of 27 inches. It costs $905 in steel, and $1,325 in stainless.

For further technical data, Circle 601 on Data Post Card.

342 Pumps, solids-handling. Bulletin PB56 from Galiger Co. gives complete technical details of the "Vacseal" pump for handling slurries and corrosive solutions.

343 Pumps, submersible. Bulletin 202 from Layne & Bowler gives technical data, cross-section drawings, applications.

344 Refrigeration Systems. New Bulletin 172 from Clark Bros. discusses relative merits of vapor compression and ammonia absorption systems for large and small gasoline plants.

345 Regulator, pressure & temperature. Bulletins and complete engineering information on new combination temperature and pressure regulator from OPW-Jordan.

346 Sampler, air. Portable, may be used for mobile or fixed position operation. Details from Staplex.

347 Strainers, line. Available in sizes from ¼ to 6 in. flange conections, in cast brass, iron, stainless steel. Bulletin from Spraying Systems.

348 Thermocouples. Newly-revised Catalog EN-S2 covers full line of thermocouples, thermocouple components, accessories. Leeds & Northrup.

349 Tubes, heat exchanger. Brochure from Scovill Mfg. gives technical data, composition, specifications.

350 Tubes, heat exchanger. Bulletin TB-431 from Babcock & Wilcox describes new line of "Lectrosonic" heat exchanger tubes.

351 Tubing, aluminum. New 48-page book from Revere Copper and Brass gives details of all types of aluminum tubing. Selection data, corrosion resistance. Many tables.

352 Tubing, reactive metals. Special Analysis Memo 121 from Superior Tube describes new line of small tubing in columbium, tantalum, vanadium.

353 Tubing, stainless, high-strength. Details from Superior Tube on new precipitation-hardening stainless analysis with outstanding mechanical properties at elevated temperatures.

354 Valves, control. Bulletin 150 from DeZurik lists bodies, actuators, accessories. Gives valve sizing data.

355 Valves, globe. Associated Valve offers technical data on its Series 1291-A and 1292-A high temperature and high-pressure globe valves, for liquid or vapor service.

356 Valves, vacuum, diaphragm-operated. Capable of sealing and holding vacuum to within 0.5 in. Hg absolute. Details from Sinclair-Collins Valve.

357 Weighing Unit, small-quantity. New "Mini-Weigh", made by Glengarry Processes, has a range of 1 to 100 grams, speed up to 15 weighings per minute. Technical details.

A.I.Ch.E. Membership

Brochure—"Know Your Institute"—tells objective aim and benefits to chemical engineers who join this nation-wide organization, includes membership blank. Circle number 600 on Data Post Card.

VITON® O-Rings seal heat exchanger at 525° F. —outlast other synthetic rubbers 25 to 1

Kontro Adjust-O-Film centrifugal processing units are commonly used as continuous evaporators. They operate by spinning the product in a thin film against a heat transfer surface. Heat exchange is extremely fast and hold-up very low, so high temperatures can be used.

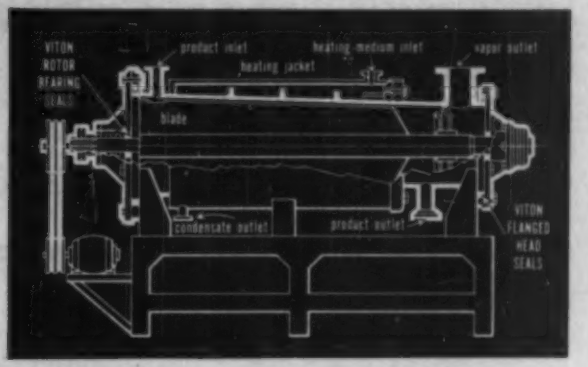
Bearing seals from pilot plant model (shown above) operated at 525° F. The one on the left was made from a standard synthetic rubber; the one on the right from VITON. Performance like this led to use of VITON on commercial models of the heat exchanger. Location of VITON seals is indicated in the diagram, right.

Expose most synthetic rubber O-ring seals to temperatures as high as 525° F. . . . subject them, at these high temperatures, to chemicals like fatty acids, dibasic acids, phthalic acid, solvents and petroleum products. Do all this, and *you know* what happens: the rubber loses its strength and resilience; it becomes useless as a sealing material. The only thing you can do is cut back your operating temperature to protect the seals.

That's exactly what The Kontro Company, Inc., had to do on one processing job for their new centrifugal heat exchanger. They had to restrict product temperature to 400° F.—125° below the 525° F. needed for optimum performance.

But that was before VITON. VITON synthetic rubber changed everything. Kontro's own tests show that VITON O-rings work just fine in intermittent operation of these heat exchangers at 525° F., lasting 12 to 25 times longer than other synthetic rubbers that have been tried.

Learn more about VITON. In O-rings, gaskets, hose, tubing and other resilient parts, you often need VITON'S ability to withstand operating temperatures of 400° F. to 450° F. continuously . . . up to 600° F. intermittently. You often need its unmatched resistance to oils, fuels, solvents, and corrosive chemicals. VITON has good mechanical properties, too—low compression set, high modulus, and good tensile strength . . . plus resistance to oxygen, ozone and weathering. Write for complete technical information to E. I. du Pont de Nemours & Co. (Inc.), Elastomer Chemicals Dept. CEP-10, Wilmington 98, Delaware.



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REG. U. S. PAT. OFF.

SYNTHETIC RUBBER

NEOPRENE
HYPALON®
VITON®
ADIPRENE®

Better Things for Better Living . . . *through Chemistry*

For more information, turn to Data Service card, circle No. 64

SPRAYING SYSTEMS CO.

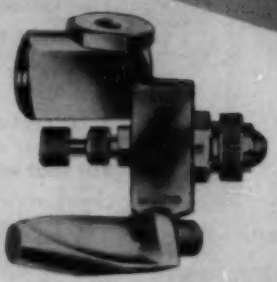
SPRAY NOZZLES

products and services

to improve your production

PRODUCTS

Whatever your application might be, Spraying Systems Co. offers spray nozzles to meet your need exactly. Over 12,000 standard nozzle types and capacities . . . to obtain whatever spray characteristics and capacities you desire in spraying, relative to any combination of liquid physical and chemical qualities.



RESEARCH

As a part of its own plant operation, Spraying Systems Co. maintains its own research facilities, for the continuing study of new spray nozzle designs, materials and applications. The many advantages of research are an inherent quality of every Spraying Systems spray nozzle you buy.

TECHNICAL INFORMATION

Complete information on spray nozzle types, capacities and performance characteristics are available in reference catalog form. Data Sheets on hundreds of basic applications are also yours for the asking. You will find Spraying Systems a reliable reference source for any information concerning spray nozzles and their application.

SPRAYING SYSTEMS CO.

3284 RANDOLPH STREET

BELLWOOD, ILLINOIS

For general information . . . Your inquiry for Catalog 24 is invited.

SPRAY NOZZLES FOR [illegible]SIBLE, MEASURABLE BETTER PERFORMANCE

future meetings

1959—MEETINGS—A.I.Ch.E.

• San Francisco, Calif., December 6-9, 1959. Sheraton Palace. A.I.Ch.E. Annual Meeting. See page 142.

1959—A.I.Ch.E.—Local Section

• Decatur, Ala. Nov. 17, 1959. Holiday Inn. Technical Symposium, Tennessee Valley Section A.I.Ch.E. For info: L. A. Allen, Jr., Chemstrand Corp., Decatur.

1959—Non-A.I.Ch.E.

• Cleveland, Ohio Oct. 20-22, 1959. Statler-Hilton Hotel. Annual Meeting Nat. Assoc. Corrosion Engrs. Contact: A. E. Long, Glidden Co., Cleveland 2, Ohio.

• Los Angeles, Cal. Nov. 2-5, 1959. IAS Bldg., 7660 Beverly Blvd. Fall Meeting. The Combustion Institute on chemical equilibria and hi-temp. performance of combustion systems. Contact: Office of Secretary, Western States Sect., Comb. Inst., 16002 Bollinger Dr., Pacific Palisades, Cal.

• Washington, D. C. Nov. 4-6, 1959. Sheraton Park Hotel. Winter Meeting American Nuclear Society. O. J. DuTemple, Sec'y. ANS, 86 East Randolph St., Chicago 1, Ill.

• Ruston, La. Nov. 5-6, 1959. Campus La. Polytech. 8th Ann. Instrumentation Conf. For info: S. Baggarly, M. E. Dept. La. Poly.

• Hamilton, Ont. Nov. 9-11, 1959. Chemical Engineering Subject Division Symposium. Chemical Inst Canada, 18 Rideau St., Ottawa 2, Ontario.

1960—MEETINGS—A.I.Ch.E.

• Atlanta, Ga., Feb. 21-24, 1960. Hotel Biltmore. A.I.Ch.E. National Meeting. Technical Program Chairman: P Bellinger, Georgia Tech. 225 North Avenue, N. W., Atlanta, 13, Ga. Student Program: H. C. Lewis, School of Ch.E., Georgia Tech., Atlanta 13, Ga. Kinetics, C. D. Holland, Ch.E. Dept. Texas A&M, College Sta., Tex.; Pesticides, (2 sessions), D. J. Porter, Diamond Alkali, Box 348, Painesville, Ohio; Nuclear Feed Materials Processing, D. S. Arnold, American Potash & Chemicals Co. Henderson, Nev.; The Textile Industry, J. E. Warren, Chem. Div., Goodyear Tire & Rubber Co., Akron 16, Ohio; High Temperature-Pressure Technology; H B. Batchelder, Battelle Memorial Inst., 505 King Ave.; Columbus 1, Ohio; Mass Transfer Applications in Waste Treatment, W. W. Eckenfelder, Manhattan College, Riverdale, N. Y. 71, N.Y.; Filtration, P. M. Tiller, Dean Coll. of Eng., U. of Houston, Houston 4, Tex.; Mineral Engineering, W. A. Koehler, W. Virginia U., Morgantown, W. Va.; Missiles and Rockets, R. B Filbert, Jr., Battelle Memorial Inst., 505 King Ave., Columbus 1, O.; Selected Papers (4 sessions Bio-Engrg.; Engrg. Education, Petroleum-Solvents, Management themes), R. J. Kyle, Eng. Exp. Sta., Georgia Tech, Atlanta 13, Ga.

• Mexico City, Mexico, June 19-22, 1960. Hotel Del Prado. A.I.Ch.E. National Meeting—Tech. Prog. Chmn.: G. E Montes, Northern Nat. Gas Co., 2223 Dodge St., Omaha 1, Nebr. Chemical Engineering in Latin America—John Mayurnik, Grace Chem. Co., 3 Hanover Square, New York 4, N. Y. Petroleum and Natural Gas Processing in Mexico & Latin America—F. W. Jessen, Dept. Petroleum Eng., U. of Texas, Austin, Tex. Financing International Projects; Optimization-Pitfalls & Potentials—W. M. Carlson, Eng. Dept., Dupont, Wilmington 98, Del. Chemical Engineering Education in the Americas—W. R. Marshall, Jr., U. of Wisconsin, Madison 6, Wisc.; Food and Biochemicals—E. L. Gaden, Ch.E. Dept., Columbia U., New York 27, N. Y. Minerals and Metals—D. B. Coghlan, Foote Mineral Co., Berwyn, Pa. Transfer Processes in Two-Phase Systems—S. G. Bankoff, Northwestern Univ., Evanston, Ill. Distillation Equipment—R. Kaisen, 3735 Dogwood Lane, Cincinnati, O. Pilot Plants—J. T. Cumming, Penn College, Cleveland 15, Ohio. Cost Estimation—R. Veorhees, Union Carbide Devel. Co., 30 E. 42d St., N. Y. 17, N. Y. Selected Papers—J. A. Samaniego, Shell Devel. Co., Emeryville, Cal.

Deadline for papers: January 19, 1960.

• Moscow, USSR, June, 1960, 1st Congress of International Fed., Automatic Control. To cover areas of Theory, Hardware & Applications of Automatic Control. U. S. participation sponsored by American Automatic Control

continued on page 134

For more information, turn to Data Service card, circle No. 138

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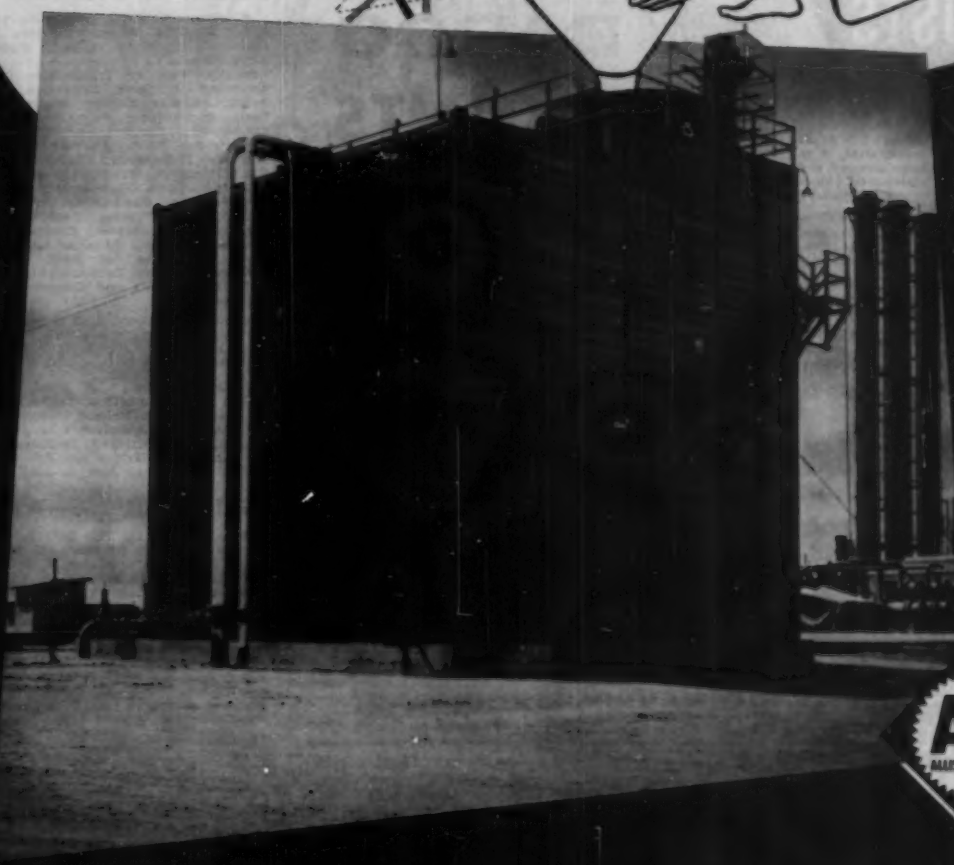

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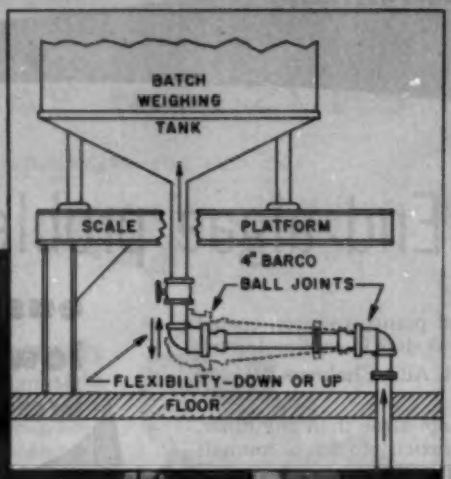

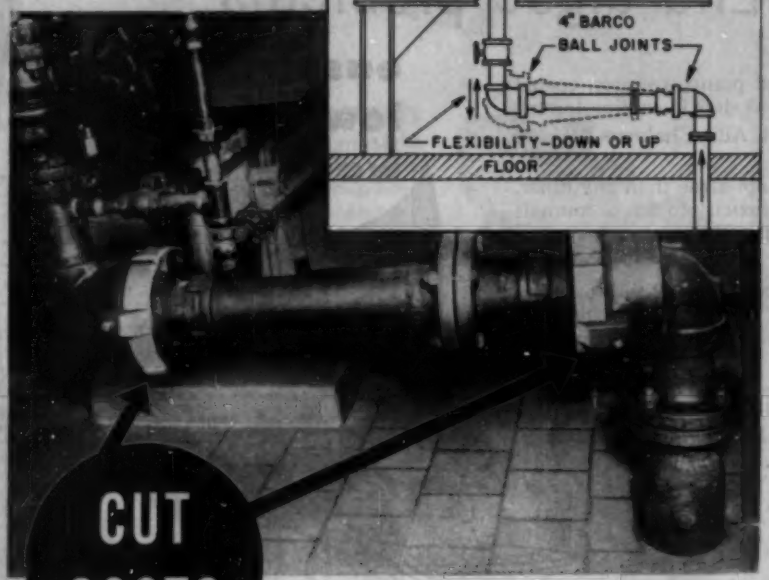

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future meetings

from page 132

Council. Affiliated societies: **A.I.Ch.E., ASME, AIEE, IRE, ISA.** A.I.Ch.E. Chmn.: D. M. Boyd, Universal Oil Prods., Des Plaines, Ill.

• Buffalo, N. Y., Aug. 14-17, 1960. Statler Hilton Hotel. **4th National Heat Transfer Conference & Exhibit.** Sponsored by **A.I.Ch.E. & ASME.** A.I.Ch.E. papers to S. W. Churchill, U. of Mich., Ann Arbor, Mich. ASME papers to J. P. Hartnett, U. of Minnesota, Minneapolis, Minn. Exhibit info to P. A. Jeculver, A.I.Ch.E., 25 West 45 St., N. Y. 36, N. Y.

• Tulsa, Okla., Sept. 25-28, 1960. Hotel Mayo. **A.I.Ch.E. National Meeting.** Tech. Prog. Chmn.: K. H. Hachmuth, Phillips Petroleum Co., Bartlesville, Okla. **Transport Processes in Petroleum Recovery**—L. P. Whorton, Atlantic Refining, Box 2819, Dallas 1, Texas; **Natural Gas & Natural Gas Liquids**—R. L. Huntington, U. of Oklahoma, Norman, Okla. **Advances in Refinery Technology**—W. C. Offutt, Gulf R&D Co., P.O. Drawer 2038, Pittsburgh 30, Pa. **Petrochemicals**—C. V. Foster, Continental Oil Co., Ponca City, Okla. & H. L. Hays, Phillips Chem. Co., Bartlesville, Okla. **Piloting, or Why Buy the Restaurant When All You Need is a Meal**—R. E. Weis, Phillips Pet. Co., Bartlesville, Okla. & D. Popovac, Continental Oil Co., Ponca City, Okla. **Corrosion & Materials of Construction**—W. A. Luce, The Duriron Co., P.O. Box 1019, Dayton 1, O., & M. S. Worley, Black, Sivalls & Bryson, P.O. Box 1714, Oklahoma City, Okla. **Statistics and Numerical Methods Applied to Engineering**—R. L. Heiny, 2709 Jefferson, Midland, Mich. **Air & Ammonia Plant Safety**—L. T. Wright, Standard Oil (Ind.), Whiting, Indiana. **Refinery & Natural Gasoline Plant Safety; Processing Agricultural Products**—A. Rose, Tex. Eng. Exp. Sta., Tex. A&M, Coll. Sta., Tex. **Area Industries; Chemical Reactions Induced or Modified by Radiation**—J. J. Martin, Ch.E. Dept., U. of Mich., Ann Arbor, Mich. **Conservation & Utilization of Water**—P. J. Lockhart, Ch.E. Dept., U. of So. Cal., 3551 University Ave., Los Angeles 7, Cal. **Foams**—C. S. Grove, Jr., Syracuse U., Syracuse 10, N. Y. & R. L. Tuve, U.S. Naval Rsch. Lab., Wash. 25, D.C. **Computers as a Management Tool**—R. Cziner, Grace Chem. Co., 3 Hanover Square, New York 4, N. Y. **Non-Newtonian Fluid Mechanics**—A. B. Metzner, U. of Delaware, Newark, Del. **Student Program. Selected Papers.**

Deadline for papers: May 2, 1960.

• Washington, D. C., Dec. 4-7, 1960. Statler Hotel. **A.I.Ch.E. Annual Meeting.** Tech. Prog. Chmn., D. O. Myatt, Atlantic Research Corp., Alexandria, Va.

Tentative Program framework: **Chemical Engineering in Govt. Programs. Agency Oriented: Nuclear Energy, Health and Education; Agriculture; Foreign Assistance Programs; Resource Development; Utilization and Reclamation; Naval Warfare Technology; Land Warfare Technology; Chemical Warfare, and Basic Research. Subject Oriented: Doing Business with the Government; Fluid Particles and Aerosols; Combustion; Materials Deterioration; New Process Techniques; Unsteady State Instrumentation; Computer Control of Processing Units; Missiles and Rockets; Design Techniques for Very Large Systems; Information and Communication; Characteristics of Portable and Expendable Plants and Equipment.**

Deadline for papers: July 5, 1960.

1960—Non-A.I.Ch.E.

• Pittsburgh, Pa., 1st Week March, 1960. **ASTM E13 Committee: Technical Symposium on Fluorescence.** Submit papers on theory or application of fluorescence or phosphorescence to Jos. W. Goldzieher, Southwest Foundation for Research & Education, P.O. Box 2296, San Antonio, Texas by Nov. 1, 1959.

1961—MEETINGS—A.I.Ch.E.

• New Orleans, La. Feb. 26-Mar. 1, 1961. Hotel Roosevelt. **A.I.Ch.E. National Meeting.** Tech. Prog. Chmn.: H. L. Malakoff, Petroleum Chem. P.O. Box 6, New Orleans 6, La. **Kinetics of Catalytic Reaction; Brainstorming Technical Problems; Petrochemicals—Future of the Industry on Gulf Coast; Future Processing Technologies in the Petroleum Industry; Education and Professionalism; Mathematics in Chemical Engineering; Liquid—Liquid Extractions; New Processes in the Area; Water from Sea Water; Materials of Construction; Evaluation of Research & Development Projects; Flow Through Porous Media.**

Deadline for papers: Sept. 5, 1960.

continued on page 138

For more information, circle No. 102

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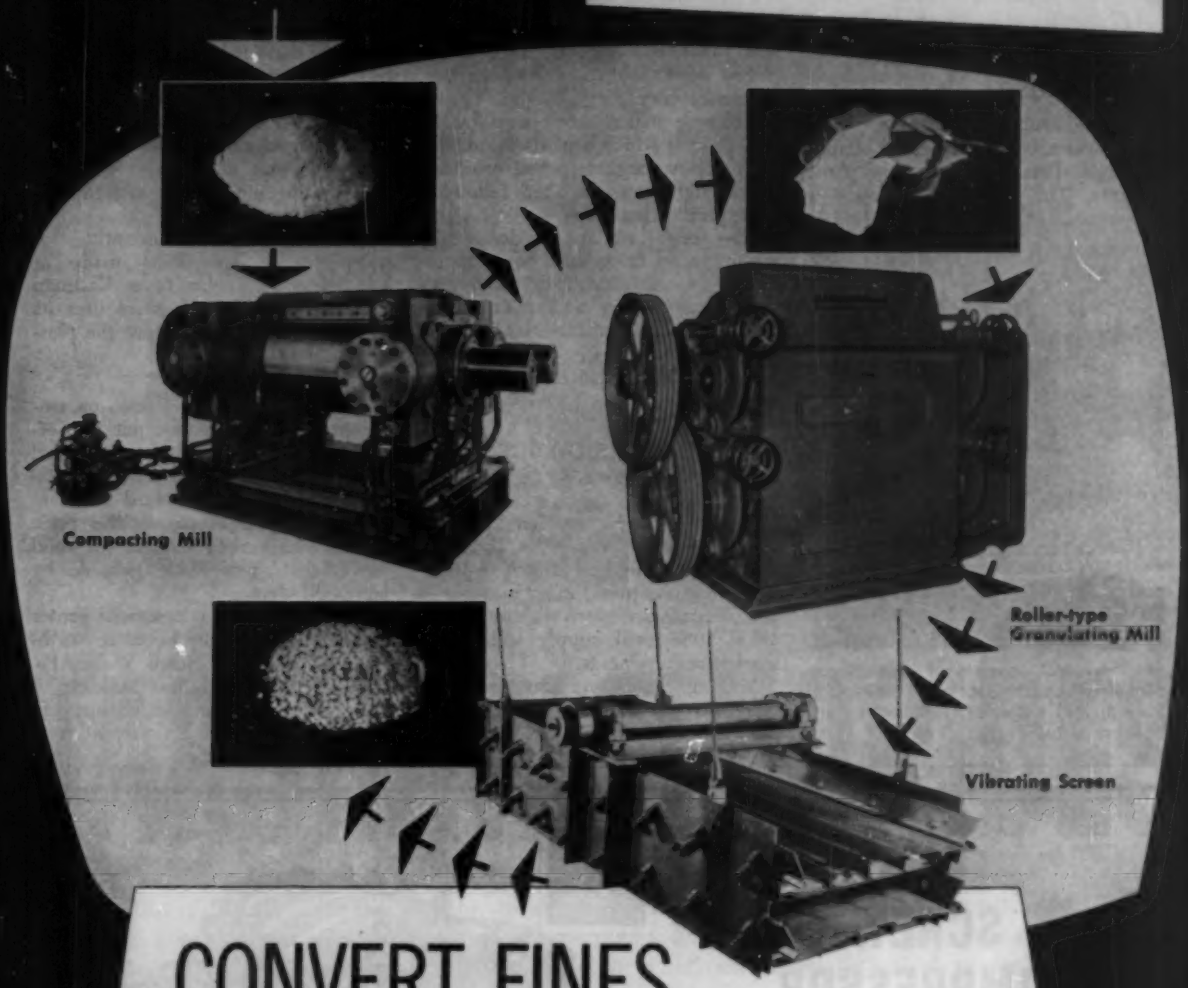

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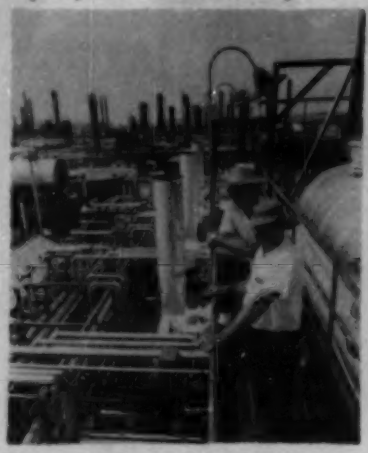
A-C ALLIS-CHALMERS

A-1191-C

Acetic acid expansion at Celanese

Celanese Chemical has just completed an expansion of its acetic acid facility at Pampa, Texas, which doubles plant capacity. The 240 million pound a year plant, the company says, is the largest acetic acid manufacturing unit in the country.



The new unit consists of high-volume centrifugal compressors and distillation towers, and major alterations to purification units.

Celanese makes acetic acid by its own process which consists essentially of partially oxidizing hydrocarbons under high pressure, then following with purification steps.

The acetic acid and its derivatives are upgraded to produce beta propiolactone, acetic anhydride, vinyl acetate, acetate esters, and other chemicals. The additional facilities will also be used to increase output of trimethylolpropane and the acrylate ester group.

More expansion for polypropylene

Facilities for polypropylene production to be built by Dow at Torrance, California, will go on stream in 1961. The Torrance plant, main location of the company's western plastics output since 1953, will supply west coast market requirements.

AviSun, which has also thrown its hat into the market, becoming the second U.S. firm to make polypropylene available in commercial quantities, has completed its 20 million pound per year unit at Port Reading, New Jersey. The unit is operated by Koppers personnel under the technical direction of AviSun, which is leasing the converted polyethylene facilities.

Limited commercial quantities of polypropylene are being made at Longview, Texas, by Texas Eastman (Eastman Kodak). Eastman uses its own process to manufacture the plastic.

A 15 percent price reduction on ammonium perchlorate just put into effect by American Potash & Chemical brings the basic price down to 29 cents a pound for standard grade in carload lots. Decrease in the price of the widely used oxident for solid fuel rockets was made possible by increased demand.

A new $2 million research center dedicated recently by Leeds & Northrup, is located at North Wales, Pa. The 65,000 square-foot building is designed for expansion to approximately three times its present size.

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- No Metal-to-Metal Contact of rotating elements
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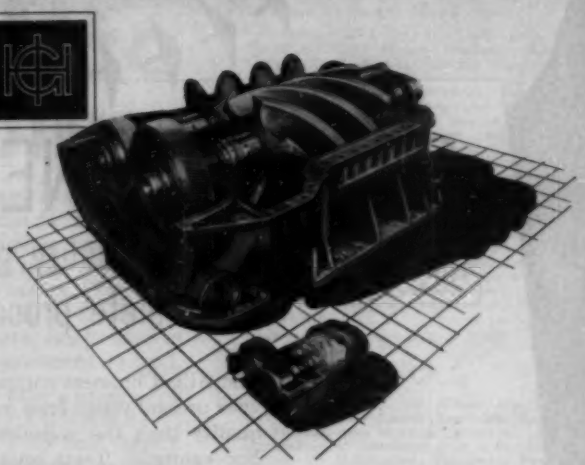

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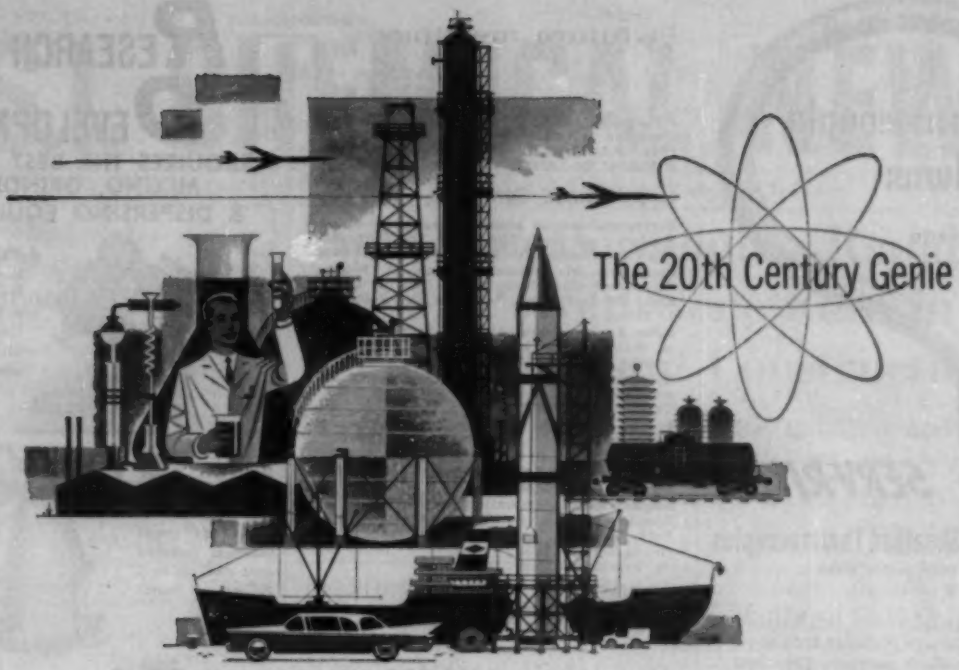

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Featuring hard-pack insulation with heavy wall construction, SERV-RITE is fully flexible and can be bent to suit requirements. In addition to a choice of junction tips, fittings and connectors, SERV-RITE *premium* sheathed wire is available in a wide range of sheath materials, bright annealed. Standard and special thermocouples are made to suit any need.

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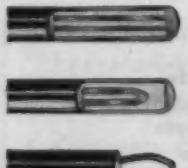

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future meetings

from page 134

• Cleveland, O., May 7-10, 1961. Sheraton-Cleveland. A.I.Ch.E. National Meeting. Tech. Prog. Chmn.: R. P. Dinsmore, Goodyear Tire & Rubber Co., Akron 10, O.

Unscheduled Symposia

Correspondence on proposed papers is invited. Address communications to the PROGRAM Chairman listed with each symposium below.

Computers in Optimum Design of Process Equipment: Chen-Jung Huang, Dept. of Chem. Eng., Univ. of Houston, Cullen Blvd., Houston 4, Texas.

Solar Energy Research: J. A. Duffie, Director of Solar Energy Laboratory, Univ. of Wisconsin, Madison, Wis.

Hydrometallurgy—Chemistry of Solvent Extraction: C. H. Beyer, Dept. of Chem. Eng., Univ. Mo., Columbus, Mo.

Process Dynamics as They Affect Automatic Control—D. M. Boyd, Universal Oil Prods., Des Plaines, Ill.

Nuclear Chemical Plant Safety—C. E. Dryden, Ohio State U., Columbus, O.

Nuclear Reactor Operations—R. L. Cummings, Atomics International P.O. Box 309, Canoga Park, Cal.

Drying—R. E. Peck, Ill. Inst. of Tech., 330 So. Federal, Chicago, Ill.

Special Courses for New York Area A.I.Ch.E. Members

Courses in Structural Planning and Design, and Engineering Economics and Practice, are available to New York area members of A.I.Ch.E. as part of a series of review study groups. Purpose is to prepare for professional engineer examinations in New York and New Jersey. The educational program, which began this month under the sponsorship of A.I.E.E. and ASME, will continue for the coming academic year.

Other courses are Basic Engineering Sciences, including practical applications of hydraulics, and thermodynamics. Also expected to be of interest are the group on Effective Speaking for Engineers, and Modern Technical Report Writing.

Registration, which is open to members of engineering groups at reduced rates, is through the educational committee of either sponsoring organization. For full details of the courses, including location of each session, write the sponsoring societies.

New bleached sulfate mill to be built at Woodfibre, B.C., Canada, by Rayonier Canada, Ltd., will have a capacity of 250 tons of high quality bleached kraft pulps a day. The company, formerly called Alaska Pine & Cellulose, is using its old mill as a site.

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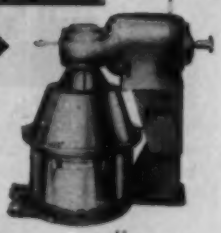

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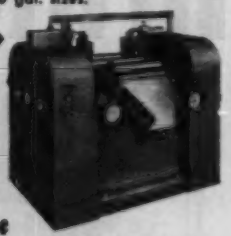

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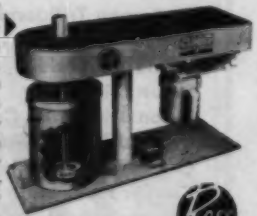

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U.S.I. CHEMICAL NEWS

October ★ A Series for Chemists and Executives of the Solvents and Chemical Consuming Industries ★ 1959

Sodium Alcoholates Act as Catalysts for Formation of Graft Polymers by Milling

Government researchers reported recently that graft polymers can be prepared by milling the component resins together on an ordinary roll mill with an anionic catalyst such as a sodium alcoholate. The reactants need not be solubilized, since reaction takes place right on the mill.

So far, styrene has been grafted onto polybutadiene and onto a copolymer of butadiene and acrylonitrile by this process. In a typical preparation, polybutadiene is milled with dispersed sodium until the mixture reaches 60°C. After cooling the rolls to 20°C., styrene is added, then propinol. Cooling stops and polymerization begins.

Temperature control is of the greatest importance to the success of the reaction. Too much heat causes gel formation; too little yields polystyrene. The researchers report that stabilizers need not be removed from the resins since they do not interfere with the grafting process. Resins can therefore be stored until used. No inert atmosphere is necessary.

Information on the preparation of sodium dispersions and their use as polymerization catalysts generally, as well as their use for sodium alcoholate preparation, is contained in U.S.I.'s brochure on Sodium Dispersions. This brochure may be obtained on request.

n-Butyl Alcohol Data Sheet Just Issued by U.S.I.

n-Butyl alcohol — solvent for coatings and resins and intermediate for plasticizers, resins, weed killers, ore flotation agents and many other compounds — is described in a new technical data sheet now available from U.S.I.

Specifications, properties, shipping and application information are included. The advantages of the material as a solvent for nitrocellulose lacquers are highlighted.

The data sheet can be obtained from U.S.I. sales offices or from the Industrial Alcohol and Solvents Sales Department at 99 Park Avenue in New York.

Ether Aerosol Gives Diesels Quick Start

Ethyl ether and a lubricant have been combined in an aerosol formulation designed to permit quick starting of diesel engines in cold weather.

The formulation, recently put on the market in pressurized cans, is said to be low in cost and to perform at temperatures down to minus 60°F. Advantages cited for this priming fuel include: reduced dilution and wear, minimizing of strain on engine parts and batteries, prevention of downtime, elimination of towing and extra labor costs.

New Uses Developing Rapidly For Polyethylene Film in Chemical Plant Construction

Film Makes Ideal Moisture Barrier for Buildings and Roads; Protects Construction Machinery, Equipment and Materials.

The ready availability of low-cost polyethylene film in a wide range of widths, lengths and thicknesses is changing the face of the construction industry. New building practices and techniques are evolving rapidly to take advantage of the excellent moisture barrier characteristics, strength and light weight of the material.

Another great advantage in construction work is the durability of polyethylene film. It has great toughness and elasticity and will take considerable abuse without tearing. It stays flexible under all types of weather conditions.

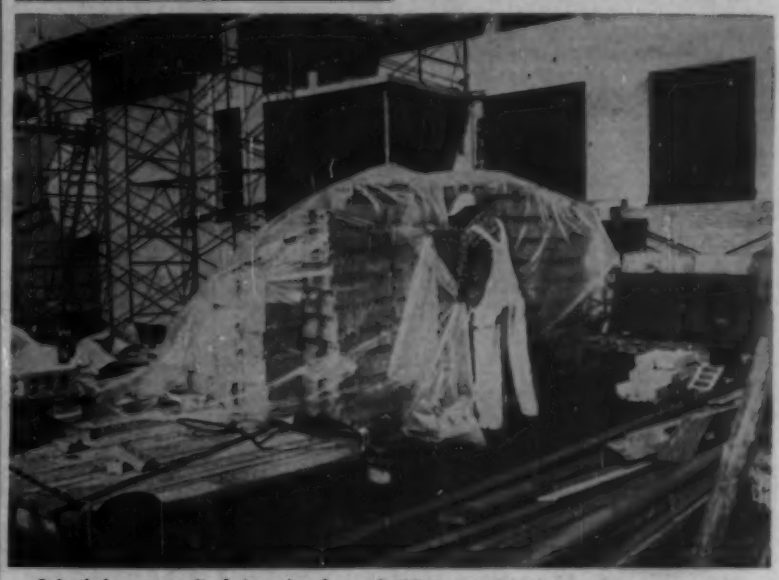
Film Valuable in Concrete Work

Constructors of chemical plants, commercial buildings, homes and other structures are employing polyethylene film for three general types of jobs: in concrete work; as a vapor barrier for interiors; as a protective covering.

As a curing agent for concrete slabs, polyethylene film laid over the watered, hardened concrete retards evaporation and allows the slab to age slowly, giving maximum hardness. The sheet can then be used again, either for the same type of job, or under a foundation slab or concrete road section as a moisture barrier base.

Because of its flexibility, strength and light weight, polyethylene film has proved

MORE



Polyethylene tarpaulin being placed over building materials during plant construction.

New Analysis for Naphthas Uses Gas Chromatography

At the ACS meeting at Atlantic City in September, it was reported that a shortened analysis for olefin-free naphthas has been developed. Gas chromatographic methods, using ethyl chloride as an internal standard, is said to give the content of C_5 and lighter components in these naphthas in one-third the time formerly required by standard low-temperature fractional distillation (LTFD) methods.

The naphtha sample, blended with ethyl chloride, is injected onto Silicone 200 on a column of Celite. The technique involves reversing the flow of the helium carrier gas after *n*-pentane has come off, to backflush the heavier components from the column.

In addition to the time-saving aspects of the new method, it is claimed to give outstanding reproducibility as well as improved accuracy over the LTFD method.

CONTINUED

Polyethylene Film

easy to handle in concrete work, and cuts down on tearing, which has been a problem with many other materials.

New Use in Tilt-Up Construction

In tilt-up slab concrete construction, polyethylene film is being used as a bond-breaking barrier. A layer of film is laid on the surface on which the slab will be poured, to separate it from that surface. After drying, the poured slab can be tilted up from the surface quickly and easily. Its undersurface is smooth, and it has received a strong, even cure because of the moisture barrier characteristics of the film.

In the pouring of foundation walls, polyethylene film is being employed to line the forms for smooth finish and better curing. It is then attached to the walls before backfilling, to act as a moisture barrier for the completed foundation.

Polyethylene film acts as an excellent moisture barrier on side walls and ceilings, in the water-proofing of beams, in the flashing of stone and brick sills, for flashing window and door heads in masonry construction—in short, for all types of moisture-proofing work on buildings.

Film Protects Work and Personnel

Finally, chemical constructors find that polyethylene film gives excellent protection from the weather — for men, structures, equipment, machinery and materials. On unfinished buildings, it keeps out wind and dirt while permitting the sun's light and heat to enter. Work can continue, uninterrupted by cold or storm. And as a tarpaulin, polyethylene film is light and easy to handle — provides the most inexpensive protection available for expensive equipment.

The future of polyethylene in the building industry continues to be brightened by new applications. For example, "bubble houses" held up by air pressure show promise as economical shelters for construction work or temporary storage. New uses such as these promise to further the spectacular growth which has been characteristic of polyethylene in recent years.

Another New UV Absorber Developed for Polyethylene

A metal-organic stabilizer has been developed to protect polyethylene film, sheet and monofilaments against deterioration from ultraviolet action during outdoor exposure. It is claimed that a two- to five-fold increase in the useful life of the finished product can be obtained through incorporation of this stabilizer into the resin.

The compatability of the product with polyethylene and its high thermal stability are said to make it suitable for low-gauge films where, because of the high ratio of surface area to volume, conventional UV absorbers are not too effective.

As little as 0.25% of the product has been found to give effective stabilization. However, 0.5% is generally recommended. At these concentrations, the very slight green color imparted is reported to be negligible, particularly in low-gauge stock. The material is also recommended for use with polyolefins other than polyethylene.

The following typical weathering data is given for conventional polyethylene:

Percent Elongation Versus Hours of Accelerated Weathering*

Stabilizer Concentration, %	Hours of Exposure		
	0	150	250
0.0 (unmilled sample)	545	105	26
0.0 (milled sample)**	388	85	8
0.2 (milled sample)**	400	366	175
0.5 (milled sample)**	262	247	252

*Accelerated weathering conducted in Fade-O-Meter. Five-mil, extruded film used for tests.

**Standard procedure includes 10-minute milling of resin and additive, at or near melt temperature of respective resins, on 2-roll plastics mill, to insure complete dispersion.

TECHNICAL DEVELOPMENTS

Information about manufacturers of these items may be obtained by writing U.S.I.

New, all-inorganic zinc coating is designed to give high galvanic protection and to eliminate sub-film rusting in fresh and salt water, solvents. Claimed effective from —60°F to +750°F. Can be used as single coat or as prime coat. **No. 1520**

Handbook on properties of rare earth metals and compounds is now being sold. Brings together for first time current data on physical, crystal, chemical, mechanical, electrical, magnetic, nuclear and thermodynamic properties of the 15 rare earth metals plus yttrium. **No. 1521**

Electron beam welding process has been developed for zirconium, hafnium, tantalum and other reactive metals impossible or very difficult to weld by ordinary means. Uses high intensity beam in high vacuum. **No. 1522**

Fact file on titanium and titanium alloys can now be obtained. Booklet contains sections on high temperature performance, corrosion and erosion resistance, properties, metallurgy, machining, fabrication, welding and testing. **No. 1523**

New use for molecular sieves — to both store and tame a large number of chemical compounds which are extremely volatile, toxic or reactive — is described in a booklet now available on chemical-loaded molecular sieves. **No. 1524**

Phospho and silico molybdic acids are now being produced in experimental quantities. Suggested for use in analyses and in petrochemical and pigment fields, as catalysts, organic precipitants and corrosion inhibitors. **No. 1525**

An atomic industry directory of products, equipment and services can now be purchased. Gives product and service profiles of over 200 industrial organizations active in development and use of atomic energy here and abroad. **No. 1526**

Colorimetric unit for quick-testing of low concentrations of dissolved oxygen in boiler feedwater is now on market. Claimed accurate to within two parts per billion of oxygen. Said to be easy to use by inexperienced operators. **No. 1527**

Tetranitromethane oxidizer for high-energy liquid and solid rocket and missile fuel systems is described in new data sheet. Active oxygen content is close to liquid oxygen while formulation of stable, storable fuels is easier. **No. 1528**

New pH calculator, set up like a slide rule, solves complex problems involving concentration of buffer solutions, rapidly and easily. Eliminates logarithm calculations with scales that can be read to second decimal place. **No. 1529**

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Animal Feed Products: Antibiotic Feed Supplements, Calcium Pantothenate, Choline Chloride, Special Liquid CURBAY, Menadione (Vitamin K_3), DL-Methionine, MOREA® Premix, Riboflavin Products, U.S.I. Permadry, Vitamin B_{12} Feed Supplements, Vitamin D_3.

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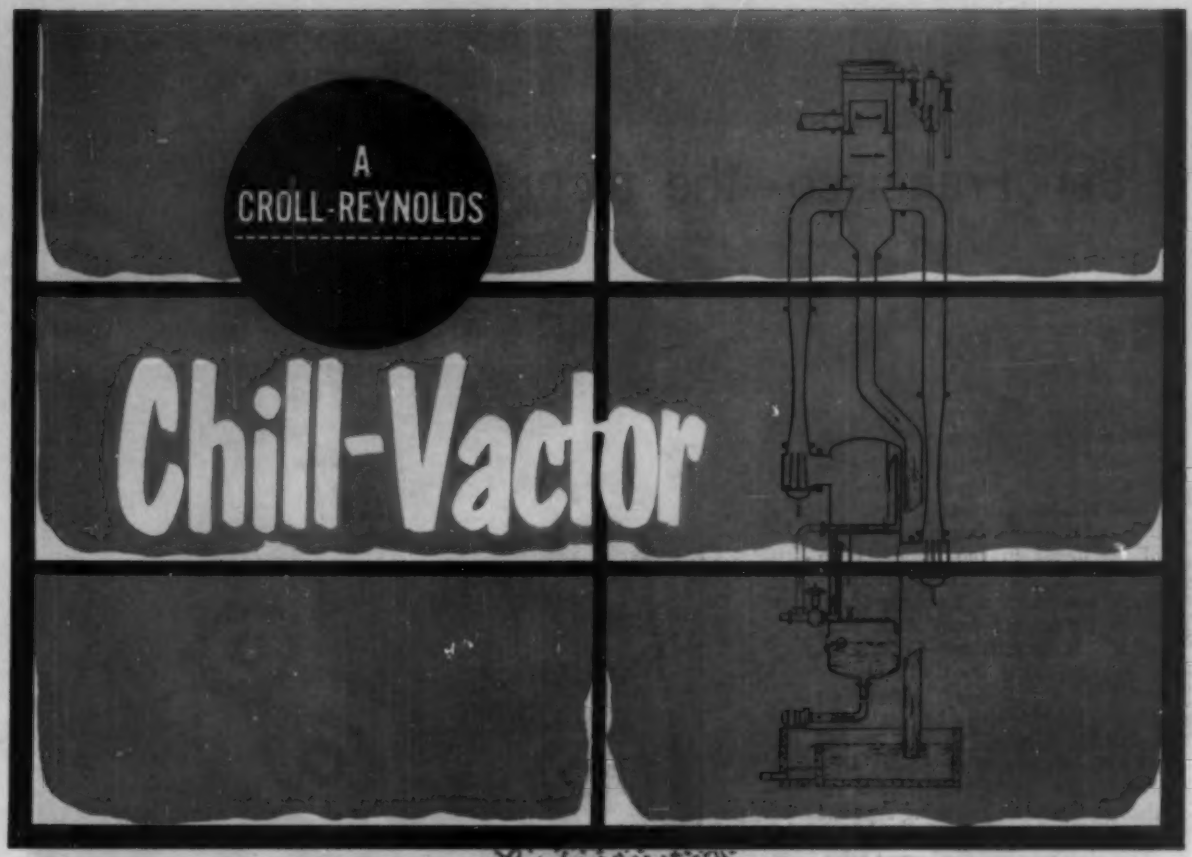

Comes Nearest to Natural Refrigeration

Nature produces refrigeration (snow, sleet, and hail) indirectly by change of atmospheric pressure to bring warm water vapor in contact with cold air.

NO CHEMICAL REFRIGERANT OR ABSORBENT TO LEAK, CORRODE OR CRYSTALLIZE

In each case, water is its own refrigerant or cold air serves the purpose. Jet vacuum refrigeration comes nearest to this natural refrigeration.

As a method of industrial refrigeration, jet vacuum refrigeration is thoroughly established and is successful in many hundreds of industrial plants in capacities varying from a few tons to 4500 tons.

The unit sketched can be placed outdoors and operated continuously or intermittently in any climate. The equipment adapts itself readily to automatic control or is very easy to control manually. The unit is self-supporting. There are no moving parts, no noise, no vibration. The maintenance and supervision required are negligible.

While most vacuum installations are used to cool water, vacuum cooling is particularly efficient for cooling chemical solutions. Instead of the usual expensive heat transfer surface, only simple corrosion-resistant vessels are needed. Some process plants have dozens of separate units totaling thousands of tons of refrigeration just for the purpose of cooling chemical solutions. Their record of savings is remarkable.

There are many other applications, too. Fresh vegetables and other moist solids are readily cooled by jet vacuum refrigeration. By adding a heat exchanger bundle inside the vacuum chamber, gases can be cooled without circulating any liquid. In some cases, the automatic de-aerating effect of vacuum cooling is important.

Many installations of old style mechanical refrigeration could be replaced profitably with vacuum refrigeration, which costs much less to buy and somewhat less to operate.

All inquiries will be given careful engineering study without obligation.

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meeting preview

San Francisco—the technical program

W. B. Hauserman
Philadelphia Quartz Co. of California, Berkeley, Calif.

Applications of digital and analog computers will be the topic of several technical sessions at the San Francisco Annual Meeting, December 6-9. Related topics in this fast-growing field will be found in the symposia on Operations Research, Process Dynamics, and Computers as Teaching Tools, and in the report from A.I.Ch.E.'s Machine Computation Committee. Along these same lines will be the special all-day Sunday lecture on "Process Development by Statistical Method," presented by C.E.P. Box and J. S. Hunter of Princeton University. (This event will have a restricted attendance requiring separate advance registration.)

This time possibly the largest selection of papers yet offered at an Institute meeting will be heard. One general session will deal with kinetics, another with thermodynamics, and others will present recent data on fluid mechanics, mass transfer, transport properties, and equipment design.

Among the varied symposia being offered, a topic of general interest will be "Outlook for Natural Re-

continued on page 144

The beauty of the countryside around San Francisco is typified by this view of world-famous Stanford University.

Three-Day Schedule of Technical Sessions

MONDAY, DECEMBER 7

2:00 to 5:00 P. M.

TECHNICAL SESSION NO. 1—FUNDAMENTAL CONCEPTS OF THERMAL METHODS OF RECOVERY OF PETROLEUM—IN SITU COMBUSTION.

Chairman: F. H. Poettmann, Ohio Oil.

Heat Transfer Characteristics of Porous Rocks. I. Effective Thermal Conductivities of Porous Media Containing Stationary Fluid, Daisa Kunii and J. M. Smith, Northwestern Univ. Equations for predicting the effective thermal conductivity of beds of unconsolidated particles containing stagnant fluid.

A Theoretical Analysis of Heat Flow in Reverse Combustion, V. J. Berry, Jr. and D. R. Parrish, Pan American Petroleum. A theoretical analysis of heat flow in reverse combustion process, assuming linear flow in a homogeneous system.

Conduction—Convection in Underground Combustion, H. R. Bailey and B. K. Larkin, Ohio Oil Research Center. A model of heat flow in an underground combustion process. The results are in the form of equations and are presented in graphical form for a number of cases.

A Method of Measuring Thermal Diffusivities at Elevated Temperatures, W. H. Somerton and G. D. Boosey, Univ. of California. The method presented here is applicable to any natural rock material, and a continuous record of change of diffusivity with temperature may be obtained in the range of 150-1000°C.

TECHNICAL SESSION NO. 2 — DIFFUSION AND MIXING IN TURBULENT FLOW.

Chairman: T. Baron, Shell Development.

Turbulent Diffusion in the Core of Fully Developed Pipe Flow, L. V. Baldwin and T. J. Walsh, Case Institute of Technology. Measurements of turbulent diffusion in the central region of pipe flow used to find empirical relations between the Lagrangian and Eulerian correlation functions.

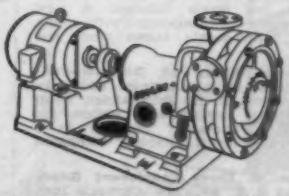
Effect of Turbulence on Drag Coefficient of Spheres in Steady and Accelerated Motion, L. B. Torobin and W. H. Gauvin, McGill Univ. Drag coefficients of smooth spheres measured with a new method to study the effects of acceleration, turbulence intensity, scale and spectrum.

Concentration Fluctuations in a Stirred Baffled Vessel, F. S. Manning and R. H. Wilhelm, Princeton Univ. Local concentration fluctuations in a stirred vessel in terms of statistical parameters which characterize various regions in the vessel.

Mixing in a Jet-Stirred Reactor, W. Bartok, C. E. Heath and M. A. Weiss, Esso Research and Engineering. Measurements of overall mixing in a gas flow reactor stirred by entering feed jets.

continued on page 144

IS THIS HAPPENING INSIDE YOUR PUMPS?



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When you pump corrosives, the inside of your pump *can* look like this. Or . . .

You can pump corrosives *without* corrosion with the Goulds-Pfaudler Fig. 3708 glassed pump. *Every surface that comes in contact with the pumpage* is protected by tough borosilicate glass fused permanently to the metal!

This glass-to-metal bond resists most acids at temperatures up to 350°F and alkalies at moderate temperatures.

You also prevent loss of product due to contamination, since glass is *inert*. Glass is *smooth*—discourages product adhesion and scale build-up.

For all the details, write for Bulletin 725.2 . . . plus a second booklet, "It's What's Inside That Counts," that gives you the inside story behind the new Goulds-Pfaulder glassed pump. Write Goulds Pumps Inc., Dept. CEP-109, Seneca Falls, New York.

GOULDS GP PUMPS

For more information, turn to Data Service card, circle No. 12

San Francisco

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sources," organized by Charles Meyer, University of California. It includes papers on estimation of raw-material reserves, geological distribution of the elements, and sea-floor mineral deposits.

For chemical engineers in the petroleum industry, several sessions are especially noteworthy. "Thermal Recovery of Petroleum by In Situ Combustion" is to be led by Fred H. Poettmann, Ohio Oil, who is also chairman of the symposium on Miscible Fluid Displacement.

Two sessions on Catalytic Cracking Stocks have been organized by Wheaton W. Kraft, Lummus. The sessions, each consisting of six papers, promise to be of special interest. Included in the symposium are papers on Cat Cracking Stocks from Middle East Crudes; Cat Cracking from Residues by the Gulf HDS Process; The Effect of Feed Stock Qualities on Fluid Cat Cracking; Effect of Catalyst Metal Poisoning on Fluid Cracking Yields.

Two major industries currently making increased use of engineers' talents are discussed in the sessions on Chemical Engineering Fundamentals in the Pulp and Paper Industry, chaired by J. L. McCarthy, University of Washington, and Electrochemical Engineering, chaired by C. W. Tobias, University of California.

The Nuclear Engineering Division of the Institute will be represented by symposia on Heavy Water Production, and one on Solvent Extraction. The Heat Transfer Division will offer several up-to-the-minute papers, and there will also be a symposium on "Problems in Jet and Rocket Combustion."

Presentation of the 1959 Professional Progress Award will be made. William R. Marshall, Jr., Associate Dean at the University of Wisconsin, winner of the Award, will talk on "The Unifying Potential of Engineering Research." Thomas H. Chilton, Institute Lecturer, will speak on "Nitric Acid by Ammonia Oxidation."

One of the high points of the program will be the non-technical panel on Creativity moderated by Chilton on Sunday afternoon. Four speakers will present views on the place of the creative individual in an industrial organization.

Three-Day Schedule

from page 142

Mixing and Contacting in Gas-Solid Fluidized Beds, J. J. van Deemter, Shell Oil. Gas exchange between dense and dilute phases described by eddy-diffusion and transfer-rate parameters used to construct a model of a reactor.

TECHNICAL SESSION NO. 3—THE TECHNOLOGY OF THE PRODUCTION OF HEAVY WATER.

Chairman: W. P. Bebbington, Du Pont.

Design and Construction of the Dana Dual-Temperature Heavy Water Plant, E. A. Comley, R. M. Reed, and N. C. Updegraff, Girdler Div., Chemetron. Design and construction of the dual-temperature section of the Dana Plant, including the laboratory and pilot plant program to select the process.

Materials of Construction for the Dual-Temperature Exchange Process for Producing Heavy Water, V. R. Thayer and W. B. De Long, Du Pont. The development program leading to the selection of materials of construction for the heavy water plants and pertinent test data.

Control of the Dual-Temperature Exchange Process for the Manufacture of Heavy Water, J. W. Morris & W. C. Scotten, Du Pont. The principles and techniques used to maintain the necessary precise control of flows in the dual-temperature process.

Production of Heavy Water by the Low Temperature Distillation of Hydrogen, G. C. Baniotes, E. Cimler, and M. C. Sze, Hydrocarbon Research. One of the most economical processes for the production of heavy water, the fractional distillation of hydrogen at low temperature.

The Future for Cheap Heavy Water, Frank T. Barr & W. P. Drews, Esso Research & Eng. Out of almost 100 ideas for new methods of manufacturing heavy water, four were found to be potentially attractive, providing optimistic critical assumptions are confirmed experimentally.

TECHNICAL SESSION NO. 4—PROBLEMS IN JET AND ROCKET COMBUSTION.

Chairman: C. J. Marsel, New York Univ.

Composite Solid-Propellant Combustion Mechanisms, Raymond Friedman, Atlantic Research. Theories and experimental evidence pertinent to the mechanism of solid-propellant combustion phenomena.

A Study of Detonation, R. A. Gross, Fairchild Engine & Airplane. Description of research with steady, standing, plane and oblique detonation waves. Experiment and theory are compared and applications (including chemical) are discussed.

Combustion Problems in High Energy Rockets, W. T. Olson, Lewis Research Center, Nat'l. Aeronautics & Space Adm. Chemical engineering problems related to the handling and combustion of high energy fuels.

A Model of Liquid Rocket Engine Combustion, R. S. Levine, Rocketdyne Div., North American Aviation. Analysis of the effect of heat and mass transfer on the combustion rate of droplets in a liquid bipropellant rocket engine.

TECHNICAL SESSION NO. 5 — SELECTED PAPERS.

Chairman: M. Manders, Union Oil of Calif.

Liquid Viscosities Above the Normal Boiling Point for Methane, Ethane, Propane and n-Butane, G. W. Swift, John Lohrenz, and Fred Kurata, Univ. of Kansas. New data on the liquid viscosities of methane, ethane, propane, and n-butane above their boiling points. Correlation for the prediction of viscosities of paraffins is included.

The Critical Temperatures and Pressures of Binary Systems, R. B. Grieves and G. Thodos, Northwestern Univ. Based primarily on binary systems, a method is presented for the prediction of critical temperatures and pressures of multi-component mixtures containing all hydrocarbon types and hydrogen.

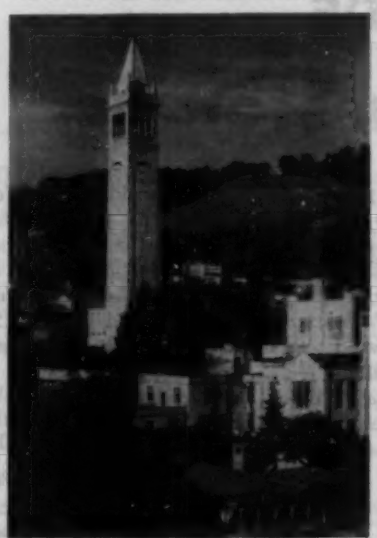
Critical Temperatures and Pressures of Organic Compounds, J. C. Forman and G. Thodos, Northwestern Univ. A method for calculation of van der Waals' constants a and b, and thus critical temperatures and pressures, for organic compounds of many classes.

Thermal Conductivity and Viscosity of Gas Mixtures, H. Cheung, L. A. Bromley, and C. R. Wilke, Univ. of California. New correlations for thermal conductivity and viscosity of gas mixtures. Experimental conductivity data for a number of binary and ternary mixtures.

Mass Transfer from a Solid, Soluble Sphere to a Flowing Liquid Stream, R. L. Steinberger and R. E. Treybal, New York Univ. New mass transfer data for single spheres. A new correlation compares excellently with some six hundred data points taken from the literature.

An Experimental Study of Diffusion-Controlled Reactions in a Laminar Boundary Layer, M. Litt and S. K. Friedlander, John Hopkins Univ. An experimental system for studying rapid second-order reaction in a laminar boundary layer. Results compared with theory.

Mass Transfer in Three Component Gases, H. L. Toor and R. T. Sebulsky, Carnegie Inst. of Technology. Equations developed and experimentally confirmed for predicting the rate of mass transfer from an interface to a ternary gas mixture in turbulent flow.



The Berkeley campus of the University of California near San Francisco.

TUESDAY, DECEMBER 8

9:00 to 11:00 A. M.

TECHNICAL SESSION NO. 6—FUNDAMENTAL CONCEPTS OF MISCIBLE FLUID DISPLACEMENT.—I.

Chairman: F. H. Poettmann, Ohio Oil.

continued on page 146

CP-5 POWERED FOR NEW EXPERIMENTS

The CP-5 reactor at Argonne has been a pioneer research reactor for obtaining high neutron flux by the heavy-water, enriched-uranium principle. Basic knowledge in physics, chemistry, metallurgy, applied engineering and biological research has been advanced by experiments that depended on this reactor. Now the CP-5 design is improved to yield still higher neutron intensity and new instrumentation extending the ranges of measurement devised, making the reactor an even more important tool for Argonne scientists.

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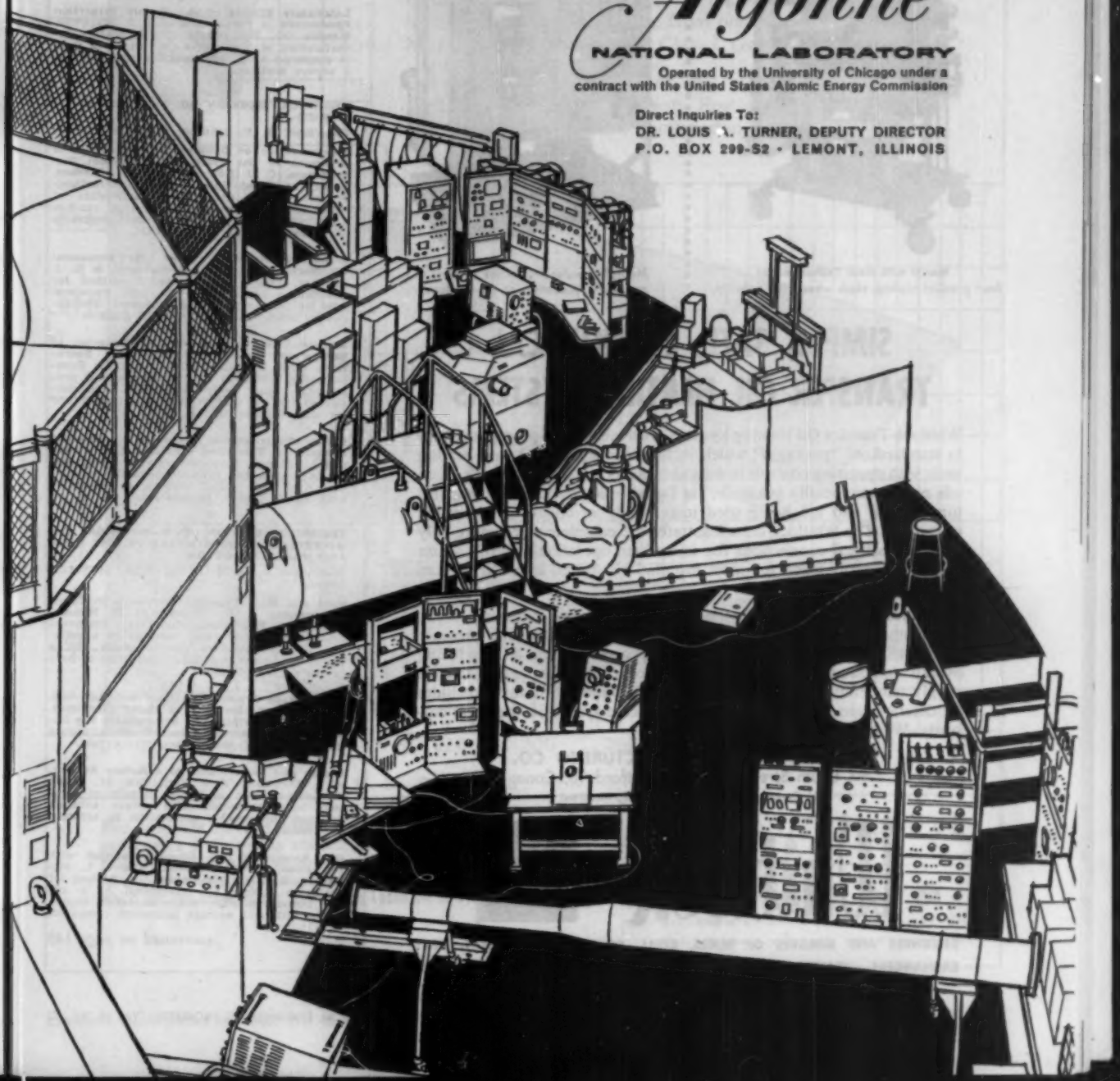
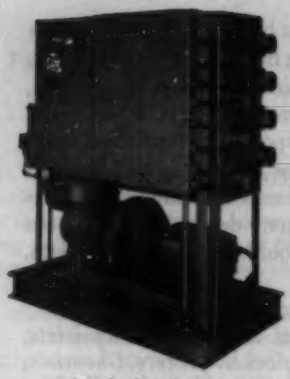
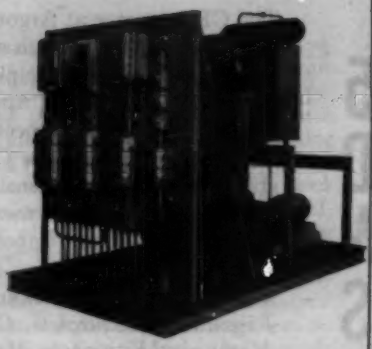


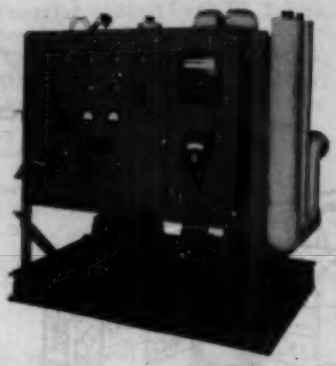


Standard Model.



Explosion-Proof Model made in Group 1 Class D Construction.

Model with Heat Exchanger for final product cooling. Note wheels for mobility.



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Since these "packages" handle the oil at low pressures, averaging 15 psi, and temperatures up to 600°F, they eliminate need for high pressure design techniques, thereby simplifying process design and reducing overall equipment cost. Carefully selected controls maintain the oil supply temperature accurately within ±2°F, and the design precludes oil deterioration. Pilot lights on panel indicate system is operating correctly. Write for information and prices.

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Technical program

from page 144

Miscible Displacement — Flow Behavior and Phase Relationships for a Partially Depleted Reservoir, J. F. Wilson, Union Oil of Calif. A qualitative theory for the slug displacement of two-phase systems proposed and found to be in general agreement with observed flow behavior.

Miscible Fluid Displacement — Prediction of Miscibility, A. L. Benham, W. M. Dowden, and W. J. Kunzman, Ohio Oil Research Center. A relatively simple method for calculating the approximate conditions for a miscible displacement of reservoir fluid by rich light hydrocarbon gases or by LPG mixtures.

Phase Relations of Miscible Displacement in Oil Recovery, C. A. Hutchinson, Jr. and P. H. Braun, Atlantic Refining. This paper relates and compares phase relations and mass-transfer mechanisms of various basis miscible displacement processes, and discusses effects of various operating variables.

Laboratory Studies of Microscopic Dispersion Phenomena in Porous Media, R. J. Blackwell, Humble Oil. The results of a laboratory investigation of the process by which a fluid is displaced by a fluid miscible with it from a porous medium.

TECHNICAL SESSION NO. 7—PROCESS DYNAMICS—I.

Chairman: E. P. Johnson, Princeton Univ.

Determination of Dynamic Characteristics of Processes in the Presence of Random Disturbances, C. J. Homan and J. W. Tierney, Remington Rand Univac. Statistical methods of determining dynamic characteristics of linear processes in the presence of random disturbances applied to non-linear processes simulated by digital computation.

Frequency Response From Non-Sinusoidal Waveforms, L. Iscol, C. L. Edwards, & R. J. Altpeter, Univ. of Wisconsin. A method for resolving a periodic non-sinusoidal waveform into its fundamental and harmonic frequencies by numerical Fourier series analysis.

Mathematical Analysis of the Behavior of Holdup in Transient Mass-Transfer Operations, C. E. Huckaba, Univ. of Florida. Equations for holdup in both stagewise and continuous contact equipment derived and considered for the case of invariant holdup and for time varying holdup.

A New Computational Model for the Dynamic Behavior of Fixed-Bed Reactors, H. A. Deans and L. Lapidus, Princeton Univ. A new model for predicting the dynamic behavior of complex fixed bed reactor systems by means of high speed digital computation.

TECHNICAL SESSION NO. 8—CHEMICAL ENGINEERING FUNDAMENTALS IN THE PULP AND PAPER INDUSTRY.

Chairman: J. L. McCarthy, Univ. of Washington.

Heat and Mass Transfer Transients in Cylinder Drying, A. H. Nissan and D. Hansen, Rensselaer Polytechnic Institute. Transient heat transfer and water removal on a cylinder drier investigated experimentally and a theory developed describing conduction of heat in the drying material.

Hot Surface Drying of Glass Fiber Materials, W. F. Cowan, Institute of Paper Chemistry. Experimental evidence to demonstrate the importance of internal structure of a porous material on its hot surface drying rate.

Design and Performance of a Rotary Aerator, S. A. Zieminski, F. J. Vermillion, Jr., Bruce St. Ledger, Univ. of Maine. Results of aeration tests conducted with rotary aerators designed for possible application in aeration of streams.

Gas Absorption into Aqueous Solution with Ionization, D. A. Ratkowsky and J. L. McCarthy, Univ. of Washington. A method for designing towers for absorption of a gas into aqueous solution where ionization occurs. Rates with and without ionization compared.

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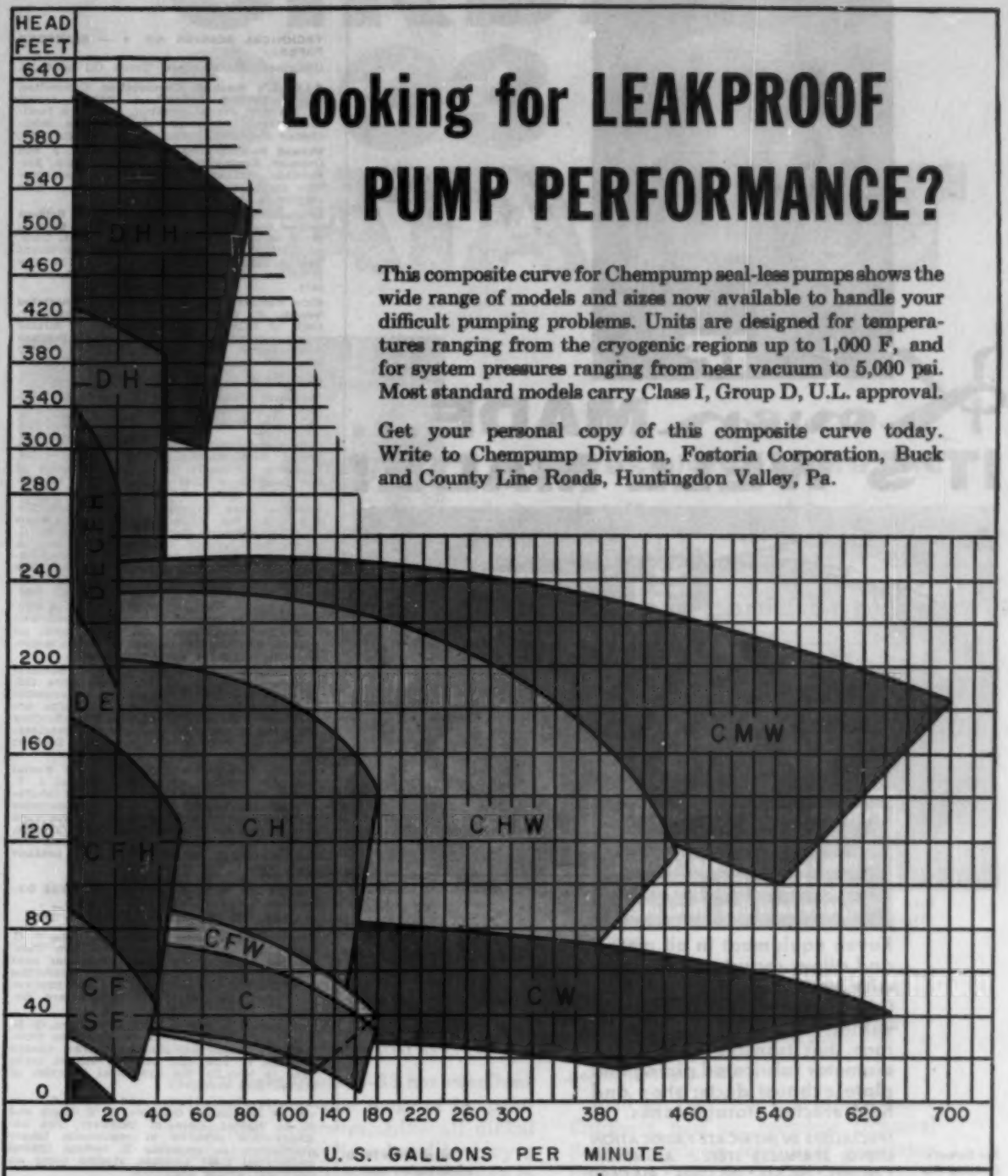

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Technical program

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TECHNICAL SESSION NO. 9 — SELECTED PAPERS.

Chairman: M. Manders, Union Oil of Calif.

A.I.Ch.E.'s Machine Computation Committee. W. M. Carlson, DuPont. A progress report on the first year's operation of a new Institute service which provides effective interchange of general-purpose computer programs.

Skewed Holding-Time Distributions, J. J. van Deemter, Koninklijke/Shell Laboratorium, Amsterdam. Statistical properties of residence-time distributions used to characterize a wide variety of types of flow reactors.

Characteristics of the Mean Flow Pattern and of the Structure in a Spiral Gas Stream, W. R. Schowalter and H. F. Johnstone, Univ. of Illinois. Profiles of mean and turbulent flow structure in spiral flow fields. The flow structure is highly sensitive to system geometry

Flow Patterns and Mixing Rates in Agitated Vessels, K. W. Norwood and A. B. Metzner, Univ. of Delaware. The prediction of mixing rates in agitated vessels attacked through measurement of the flow patterns which must determine them.

2:00 to 5:00 P. M.

Technical Session No. 10—Fundamental Concepts of Miscible Fluid Displacement—II.

Chairman: F. H. Poettmann, Ohio Oil.

Conditional Instability in Miscible Liquid-Liquid Displacement, R. L. Perrine, Calif. Research. A theory for the displacement of one fluid by another with which it is miscible within a porous medium.

Effect of Pore Structure and Molecular Diffusion on the Mixing of Miscible Liquids Flowing in Porous Media, P. Raimondi, C. H. P. Gardner, and C. B. Petrick, Gulf Res. & Dev. The authors developed and checked experimentally a mathematical expression for effective coefficient of longitudinal mixing, valid over the entire range of viscous flow.

Experiments on Mixing by Fluid Flow in Porous Media, W. E. Brigham, P. W. Reed, and J. N. Dew, Continental Oil. Experiments on miscible displacement in various porous media, and the results of these experiments.

A Comparison of Propane and CO_2 Solvent-Flooding Processes, L. W. Holm, Pure Oil. In reservoirs where pressures, oil viscosity and composition, and flooding patterns are favorable, either of these solvent-flooding processes would give oil recoveries considerably higher than conventional water flood or gas drive.

Miscible Displacement Studies Using Radial Cores, F. W. Cole, M. L. Jackson, and J. V. Cowan, Univ. of Oklahoma. Results of laboratory studies, using radial cores, to determine the displacement efficiencies of various sizes of pentane slugs followed by a water drive, and also to determine effects of varying free gas saturations on oil recovery by pentane displacement.

TECHNICAL SESSION NO. 11—PROCESS DYNAMICS—II.

Chairman: E. F. Johnson, Princeton Univ.

Distributed-Parameter Process Dynamics, W. C. Cohen and E. V. Johnson, Princeton Univ. On the basis of studies of particular heat exchange systems, the interesting properties of distributed-parameter systems and implications for their automatic control are discussed.

The Dynamics of Stirred-Tank Reactors, G. R. Marr, Jr. and E. F. Johnson, Princeton Univ. Recent experimental studies of gross mixing patterns in flow and non-flow stirred tanks used to identify the dynamical behavior of stirred tank reactors.

Dynamic Characteristics and Analog Simulation of Distillation Columns, D. E. Lamb and R. L. Pigford, Univ. of Delaware. The unsteady-state behavior of continuous binary distillation, as occurring in several typical commercial plate columns, studied using an electronic analog computer.

On the Response of Stagewise Processes to Randomly Fluctuating Inputs, A. Acrivos, Univ. of California. The response of stagewise systems to randomly fluctuating inputs formulated mathematically in a straightforward manner to yield exact solutions for linear cases.

Process Dynamics, Automatic Control, and Analog-Computer Simulation of Shell-and-Tube Heat Exchangers, L. H. Fricke, H. J. Morris.

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R. E. Otto and T. J. Williams, Monsanto. An experimental and analog-computer study of the process dynamics and automatic control of multipass shell and tube heat exchangers.

Chemical Process Control in the Presence of Both Transport Lag and Sampled Data Control, H. S. Min and T. J. Williams, Monsanto. By means of analog-computer simulation, the variation of output error and control-system settling time with increasing analysis period and reduced sampling rate is shown.

TECHNICAL SESSION NO. 12 — ELECTROCHEMICAL PROCESSES.

Chairman: C. W. Tobias, Univ. of California.

Introductory Remarks, C. W. Tobias.

Trends in Mercury Cell Design, A. G. Basilevsky, North American Solvay. Evolution in the design of mercury cells has improved product quality and safety of operation, lowered costs of operation and investment. Path to further improvement is outlined.

The Development of an Electrolytic Process for the Production of Iodates, J. C. Schumacher, American Potash & Chemical. The design, construction, and operation of an electrolytic cell for the commercial production of potassium iodate, as an application of the chemical engineering philosophy in the design of industrial electrolytic cells.

Modern Basis of Aluminum Cell Design and Operation, R. A. Lewis, Kaiser Aluminum & Chemical. Factors affecting cell design and operation. Possible solutions to the problem of increasing cell size and efficiency.

Fundamental Criteria of Fuel Cell Design, J. A. A. Ketelaar, Lab. of General and Inorganic Chemistry, Amsterdam. Thermodynamic, chemical, and operational efficiency in relation to conceptual design. Lifetime, weight, volume, fuel cost together with auxiliary equipment are factors considered in evaluation of economy.

TECHNICAL SESSION NO. 13 — CHEMICAL ENGINEERING OUTLOOK FOR NATURAL RESOURCES.

Chairman: C. Meyer, Univ. of California.

Geological Distribution of the Chemical Elements, M. Fleischer, U. S. Geological Survey. Chemical properties of the elements reviewed in the light of present and future needs of the industry for raw materials.

Future Sources of Critical Raw Materials, D. E. White, U. S. Geological Survey. High-grade sources and substitutes are still to be found. Other materials are trending to lower-grade sources. Long-term studies reveal best sources.

Mineral Deposits on the Deep Sea Floor, H. W. Menard, Univ. of Calif., Scripps Institution of Oceanography. Ferro-manganese concretions, with minor concentrations of heavy metals, occur on the sea floor in amounts up to 2-10 pounds per square foot.

Supplies of Raw Materials Used by the Chemical Industry, J. L. Gillson, DuPont. Most of the major "heavy" raw materials are ample for a long time. A few others need new reserves if the demand increases.

TECHNICAL SESSION NO. 14 — SELECTED PAPERS.

Chairman: M. Manders, Union Oil of Calif.

Design of Experiments on the Kinetics of the Water-Gas Shift Reaction, H. M. Hulburt, American Cyanamid Co., and C. D. Srini Vasan, Chemical Construction. The principles of statistical analysis used in designing experiments to determine the kinetics of the water-gas shift reaction between 310 and 340° C. and over a range of compositions.

Kinetics of the Hydrogenation of Ethylene (on a Nickel Catalyst), A. C. Pauls, E. W. Comings and J. M. Smith, Purdue Univ. The hydrogenation of ethylene on an alumina-supported catalyst, at pressures from 14.7 to 70 psia and feed compositions from 40 to 90 mole per cent hydrogen.

Hydration of n-Butene with Cation Exchange Resin, W. J. M. Douglas and R. R. White, Univ. of Michigan. A detailed rate study of the hydration of butene in the liquid phase using a strongly acidic ion-exchange resin as the catalyst.

Light Catalyzed Reactions in an Isothermal Laminar-Flow Reactor, R. S. Schechter and E. H. Wissler, Univ. of Texas. The partial differential equation describing photolysis in

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Technical program

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an isothermal laminar-flow reactor solved and the solution compared to an approximation.

Detonation Characteristics of Hydrogen-Oxygen Mixtures at High Initial Pressures, R. L. Gealer and S. W. Churchill, Univ. of Michigan. Detonation velocities of H_2-O_2 mixtures measured, and theoretical detonation characteristics computed for initial pressures from 14.4 to 1,000 psia.

Turbulent Flow of Gas Through a Circular Tube with Chemical Reaction at the Wall, R. H. Wissler and R. S. Schechter, Univ. of Texas. The concentration profiles in a turbulent gas stream flowing in a circular tube with chemical reaction at the wall determined theoretically.

WEDNESDAY, DECEMBER 9

9:00 to 12:00 A. M.

TECHNICAL SESSION NO. 15 — QUALITY CRITERIA FOR CATALYTIC CRACKING STOCKS & METHODS OF PREPARATION.

Chairman: W. H. Kraft, The Lummus Co.

Catalytic Cracking Feedstocks Derived from Middle East Crudes, R. J. H. Gilbert, and W. N. N. Knight, B. P. Trading Ltd. The properties, methods of preparation and operating results for catalytic-cracking feedstocks from Middle East crudes.

Catalytic Cracking Charge Stocks Prepared from Residues by the Gulf HDS Process, H. Deuther and R. A. Flinn, Gulf Research & Development. Heavy fuel oil can be completely eliminated and residues converted to a high quality, sulfur- and vanadium-free gas oil by hydrodesulfurization.

"Cat Cracker Feed Contamination — A Case History", E. C. Herthel, E. H. Reynolds and J. H. Roe, Richfield Oil. Improved vacuum-distillation-unit fractionation was Richfield's solution of poor fluid catalytic cracking unit operation resulting from metals contamination of feed stock.

Characterization of Catalytic Cracking Stocks, H. E. Reif, R. P. Kress, and J. S. Smith, Sun Oil. Equations, relating physical and chemical properties of charge stocks to the yields of cracked products, derived from data on a wide variety of stocks.

The Effect of Catalyst Metal Poisoning on Fluid Cracking Yields, E. C. Gossett, Sinclair Research Labs. The effect of catalyst metal poisons on cracking yields with clay and synthetic catalysts determined on a pilot-plant fluid unit.

Processing of Feed Stocks for Catalytic Cracking, K. K. McMillin, Humble Oil & Refining. An integrated system employed to provide additional cracking feed and also to improve cracking characteristics of both virgin and recycle feed streams.

TECHNICAL SESSION NO. 16—OPERATIONS RESEARCH AND PROCESS ENGINEERING.

Chairman: R. R. Hughes, Shell Development.

The Optimum Solution in Operations Research, J. C. Ornea and P. Stillson, Shell Development. Operational, technological, and investment objectives discussed, using three separate formulations of the same typical problem from the petroleum industry.

Short-Range Production Planning of Continuous Operations, D. J. Wilde and A. Acrivos, Univ. of California. A method for automatically scheduling production rates in certain systems of continuously operating manufacturing processes.

Operations Research in Chemical Plant Design, P. H. Butterfield, Stanford Research Institute. The design of new process facilities can affect the scope of later operating decisions, and thus the profitability of the plant.

Use of a Large Computer in Making Economic Designs, J. W. Kellett and A. S. Perley, Esso Research & Eng. The use of computers in process design has already led to improved designs, but the big payoff will come from automatic optimization of design.

Simulation and Optimization of Oil Refinery Design, E. Singer, Shell Development. Three new nonlinear optimization techniques applied to a simulation of a ten-variable oil refinery. All designs calculated satisfy product specifications, material balances, and operability limits.

TECHNICAL SESSION NO. 17—HEAT TRANSFER.

Chairman: J. O. Knudsen, Oregon State College.

Heat Transfer in Reacting Systems: II. Heat Transfer to N_2O_4 Gas Flowing Normal to a Heated Cylinder, F. P. Boynton, J. L. Richardson and D. M. Mason, Stanford Univ. Rates of forced-convection heat transfer from an electrically heated cylinder to a reacting N_2O_4-NO_2 system measured at various cylinder Reynolds numbers.

Power and Heat Transfer Characteristics of the Anchor Agitator, V. W. Uhl and H. P. Vosnick, Bethlehem Foundry and Machine. Heat transfer and power studies with anchor agitators in 50-gallon and 2-gallon test kettles using cylinder oil. Design recommendations.

Heat Transfer to Fine Wires and Particles by Natural Convection, T. Tsubouchi and S. Sato (to be presented by S. W. Churchill, Univ. of Michigan) Tohoku Univ., Sendai, Japan. By using thermisters as heat-transfer elements, experimental data have been extended to small Grashof numbers. A new correlation.

Heat Transfer to Particles by Forced Convection, T. Tsubouchi and S. Sato, Tohoku University, Sendai, Japan (to be presented by S. W. Churchill, Univ. of Michigan). A correlation including effects of both forced and natural convection down to Reynolds numbers of 10^{-3}.

Local Shell-side Heat Transfer Coefficients and Pressure Drop in a Tubular Heat Exchanger with Orifice Baffles, K. S. Lee and J. O. Knudsen, Oregon State College. Local shell-side heat transfer coefficients and pressure losses measured in a model tubular heat exchanger containing orifice baffles.

Application of Boundary Layer Theory to Predict the Effect of Heat Transfer on Flow Field in a Vertical Tube with a Constant Temperature Wall, Edward M. Rosen and T. J. Hanratty, Univ. of Illinois. Approximate solution of the equations of motion and energy to predict effects of density and

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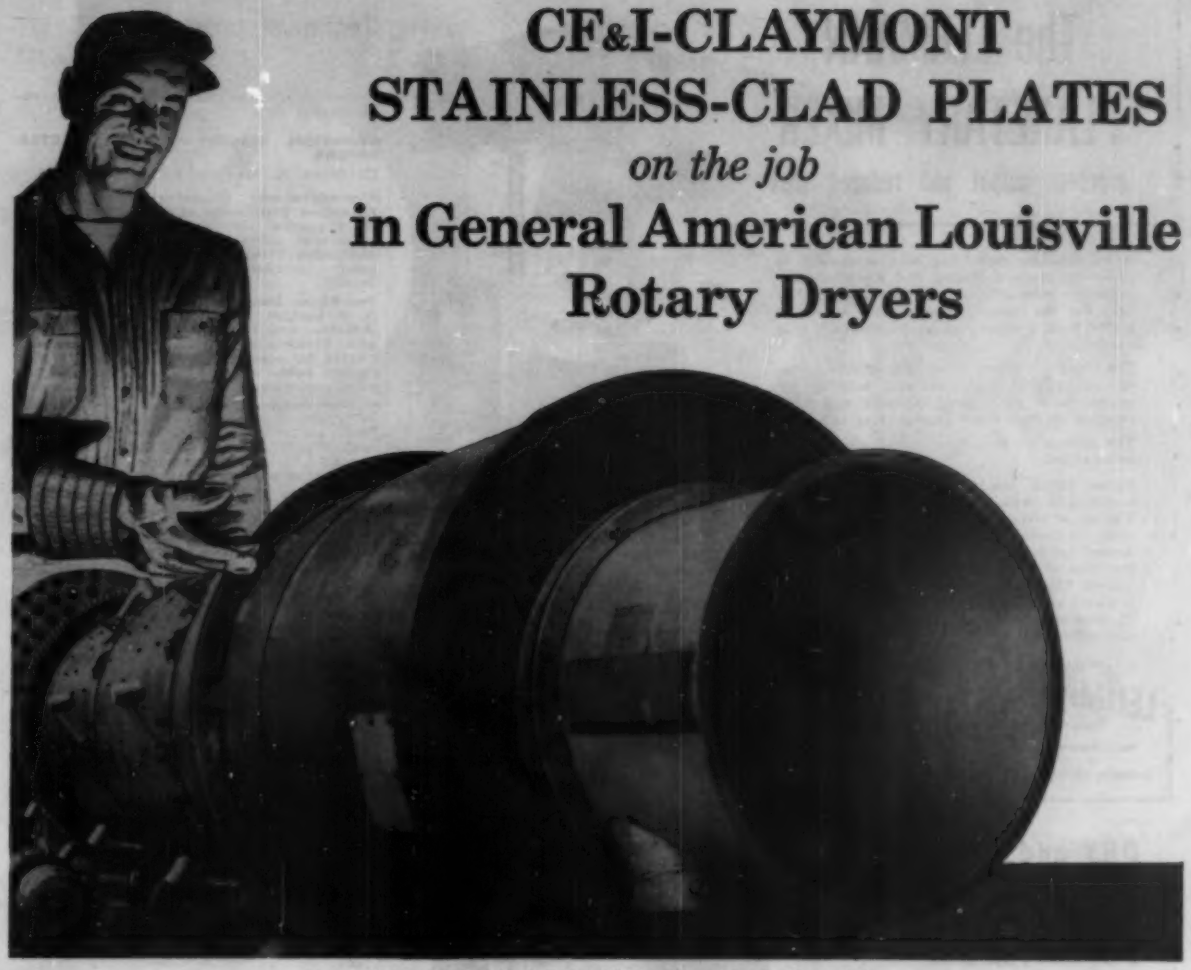

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viscosity variations. Results confirmed by experimental data.

TECHNICAL SESSION NO. 18 — SELECTED PAPERS.

Chairman: M. Manders, Union Oil of Calif.

Thermodynamics of Solvent Selectivity in Extractive Distillation of Hydrocarbons. John M. Prausnitz, Univ. of California. Analysis of solvent selectivity shows that extractive distillation depends on both polar and nonpolar contributions to cohesion energy density.

Two-Phase Cocurrent Flow in Packed Beds. R. P. Larkins, D. W. Jeffrey, Humble Oil & Refining, and R. B. White, Univ. of Michigan. Pressure drop and liquid hold-up correlated for cocurrent, gas-liquid flow through packed beds. A wide range of packing and fluid properties studied.

A New Apparatus for Liquid-Phase Thermal Diffusion. E. Von Halle and S. H. Jury, Univ. of Tennessee. A thermal diffusion column which eliminates forgotten-effect and parasitic-remixing inefficiencies. Experimental results and a phenomenological theory.

Solid-Liquid Phase Behavior of Binary Solutions at Elevated Pressures. J. Winnick and J. E. Powers, Univ. of Oklahoma. The formation of a solid phase in a binary solution with increasing pressure analyzed from a thermodynamic viewpoint. Experimental data on the n-heptane-benzene system.

The Compaction of Granular Solids. B. E. Kurtz, Allied Chemical, and A. J. Barduhn, Syracuse Univ. A mechanism for the compaction of fine granular solids between rolls to produce dense, mechanically strong particles postulated and design equations derived.

Plate Efficiencies in Multicomponent Distillation. H. L. Toor and J. K. Burchard, Carnegie Institute of Technology. A method for predicting plate efficiencies in ternary systems, and the effects of diffusional interactions in a distillation column.

TECHNICAL SESSION NO. 19 — QUALITY CRITERIA FOR CATALYTIC CRACKING STOCKS & METHODS OF PREPARATION.

Chairman: W. W. Kraft, The Lummus Co.

Propane Deasphalting for the Production of Catalytic Cracking Feed. J. G. Ditman, Foster Wheeler Corp. Economic studies based on pilot deasphalting in a rotating disc contactor show the advantages of high efficiency deasphalting for the production of catalytic cracking feed.

Effects of Feed Boiling Range in Fluid Catalytic Cracking. R. L. Plander, J. G. Girard and B. D. Laughlin, Calif. Research. Product yields and qualities for Arabian gas oil cracking related to fresh feed and recycle boiling range.

Use of Furfural Refining to Improve Catalytic Cracking Feed Stocks. R. R. Dickinson and C. B. Longsworth, Texaco. Texaco's commercial furfural refining operations and catalytic cracking yields from upgraded feed stocks.

Preparation of Feedstocks for Catalytic Cracking. R. J. Hood, The British American Oil Co. Ltd. Operating data, gas oil yields and properties as produced by processing units of The British American Oil Company Ltd. Units reviewed are: Propane Deasphalting, Delayed Coking, and Vacuum Reduction.

Solvent Extraction of Virgin Feedstocks. P. T. Atterid and R. P. Cox, The M. W. Kellogg. Phenol extraction of virgin catalytic cracking charge stocks is economically justified today because it permits production of less residuum and more cracking feed.

TECHNICAL SESSION NO. 20—SOLVENT EXTRACTION.

Chairman: O. H. Beyer, Univ. of Missouri.

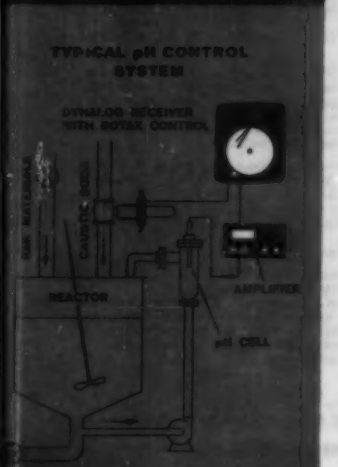
Spectral Evidence for Complex Formation in the Tributyl Phosphate-Water-Nitric Acid System. T. J. Collopy and J. F. Blum, National Lead. Spectral data which indicate that tributyl phosphate and nitric acid react to form a stable equimolar complex.

Complex Formation in the Neodymium Nitrate-Tributyl Phosphate-Water System. H. E. Bostian and Morton Smutz, Iowa State College. Three tributyl phosphates prepared and evaluated. Complexing in the organic phase found to obey stoichiometric laws.

Purification of Promethium by Liquid Extraction. B. Weaver and F. A. Kappelmann.

continued on page 156

For more information, circle No. 8



at Sika Chemical—

REACTORS CONTROLLED WITHIN 0.1 pH

by Foxboro DYNALOG* Recorder-Controllers

At Sika Chemical Corp., Passaic, N. J., control of pH in reactors is of vital concern in manufacturing "Plastimet," Sika's widely-used concrete densifying additive.

Sika finds Foxboro Dynalog Recorder-Controllers perfect for the job. Dynalog's smooth variable air capacitor (which replaces troublesome step-by-step slidewires) responds instantly to the smallest change in pH value. A Rotax on-off control unit then initiates addition of enough caustic soda to return reactor pH to set point.

Sika reports maintenance on their Dynalogs has been almost nil. One tube replaced in three years. No lubrication ...no cleaning...no dry cells to standardize or replace. "In fact," says process engineer Gordon Morrison, "we're so confident of Dynalog's performance that our reactors run right through the night—unattended."

Dynalog Electronic Recorders—Controllers—Indicators deliver accurate, sensitive, measurement not only of pH, but of dozens of other variables as well. Get full details by writing for Bulletin 20-10. **The Foxboro Company, 9310 Neponset Ave., Foxboro, Mass.**

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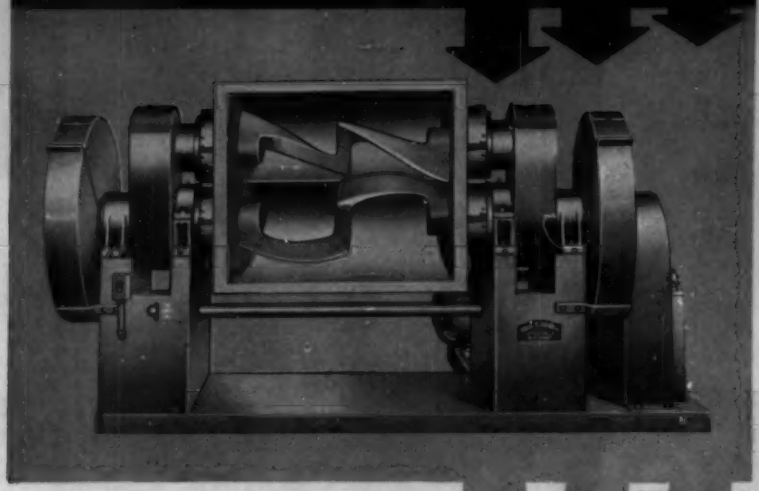
DYNALOG ELECTRONIC INSTRUMENTS

new mass & paste mixers



reduce maintenance, assure freedom from contamination.

These new heavy duty mass and paste mixers have many features which sharply reduce maintenance needs. They have double rows of lifetime lubricated bearings. These bearings give long, trouble-free performance without maintenance or lubrication of any kind under the most severe operating conditions. They are extremely low-friction bearings and can be used at elevated temperatures.

All gears are protected from dust and dirt by guards which remain in place whether the bowl is in the horizontal or the dumping position. Doors in the guards simplify lubrication of the gears.

Improved seals, easily accessible for maintenance, assure freedom from contamination.

Made in a range of sizes from 3 to 300 gallons capacity, the mixer illustrated has a mixing volume of 150 gallons.

These improved mixers are available in various materials of construction. Jackets for heating and cooling can be installed around the mixer bowl, if desired. Various styles of mixer blades can be furnished to ensure the most effective mixing and blending of a wide variety of materials.

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For more information, turn to Data Service card, circle No. 92

Technical program

from page 154

Oak Ridge Nat'l. Lab. A process for separation of promethium from fission-product rare earths by liquid-liquid extraction using pure tributyl phosphate.

The Effect of Plate-Wetting Characteristics on Pulse-Column Extraction Efficiency, R. H. Sebotik and D. M. Himmelblau, Univ. of Texas. Liquid extraction of acetic acid from the methyl-isobutyl-ketone, water system studied as a function of plate-wetting characteristics and other variables.

Stagewise Analysis of a Pulse Column, L. E. Burkhart, and R. W. Fahien, Ames Laboratory, Iowa State College. The design of a pulse extraction column, assuming it to be a stagewise process, discussed and illustrated with experimental data.

TECHNICAL SESSION NO. 21—THE AUTOMATIC COMPUTER AS A TEACHING TOOL.
Chairman: W. P. Stevens, Northwestern Univ.

Digital Computers — Their Availability and Suitability for Use as Teaching Tools in Engineering, W. P. Stevens, Northwestern Univ. The importance of introducing contact with digital computers into the engineering undergraduate program. Typical machines described and evaluated.

Chemical Engineering Calculations Using Digital Computers, J. W. Tierney, Remington Rand Univac. The unique properties of digital computers. Solutions for some sample problems.

Optimization and Its Importance to Chemical Engineering, R. C. Johnson and S. M. Roberts, Thompson-Ramo-Wooldridge. The importance of optimization indicated and various mathematical tools useful in optimization discussed. The application of digital computers to such calculations.

Available Analog Computers and Their Use as Teaching Aids in Engineering, T. J. Williams and Verlin A. Lauher, Monsanto Chem. Co. A comprehensive listing of analog computers suitable for use as teaching aids. Along with a recommended component listing for a typical classroom machine.

Unsteady-State Behavior of Chemical Processes, D. E. Lamb, Univ. of Delaware. A discussion of the reasons for emphasizing unsteady-state behavior in chemical engineering education, plus a description of an existing process-dynamics course utilizing the analog computer.

TECHNICAL SESSION NO. 22—SELECTED PAPERS.
Chairman: M. Manders, Union Oil of Calif.

Influence of Vessel Diameter on the Rate of Carbon Oxidation in Fluidized Bed Reactors, R. G. Minet, United Engineers & Constructors, and John Happel and W. Kapfer, New York Univ. Carbon oxidation studies in three different diameter reactors correlated using a pseudo-bubble-velocity time concept proposed for design scale-up calculations.

Fluidized Bed Coating — A New Chemical Process, J. Gaynor, General Electric. A new chemical process, fluidized bed coating. The role of fluidization phenomena and variables in coating.

Holdup and Pressure Drop with Gas-Liquid Flow in a Vertical Pipe, O. A. Hughmark and B. S. Pressburg, Louisiana State Univ. A new correlation for air-liquid flow in a vertical pipe. The correlation is based on experimental data obtained with six different liquids.

Simultaneous Flow of Liquid and Gas Through a Vertical Pipe, M. R. Tek and J. V. Jun, Univ. of Michigan. A new method for prediction of pressure drops occurring in vertical two-phase systems. Correlation charts and practical calculation methods.

Turbulent Convective Heat and Mass Transfer from Accelerating Particles, I. S. Pasternak and W. H. Gauvin, McGill Univ. The rate of evaporation of acetone from single particles accelerating freely in a downward cocurrent turbulent air stream studied over a range of air velocities.

A Scintillation Method for Determining Liquid-Liquid Interfacial Areas, G. J. Mitsis, R. R. Plebuch and K. F. Gordon, Univ. of Michigan. A scintillation technique with tritium developed to measure interfacial areas in highly stirred liquid-liquid systems. Results for ten configurations.

For more information, circle No. 133

THE MODERN TREND IN OIL REFINERIES

HUDSON Solo-aire units pictured above operate in a large Texas Gulf Coast Refinery, in which Solo-aires are used for a complete range of refinery services, transferring 300 million BTU's per hour directly to air.

Over-all economic comparisons of HUDSON Solo-aire cooling versus water cooling for new refining units almost invariably result in selection of Solo-aire units for much or all process cooling.

In two complete 40,000 barrel sea-side refineries now being constructed abroad by one of the world's largest refiners, HUDSON Solo-aire units will be used for ALL process cooling services. NO WATER WILL BE USED FOR PROCESS COOLING.

In the United States in a 40,000 barrel refinery being built adjacent to an unlimited water supply, 50% of the total dissipated heat will be transferred directly to air through HUDSON Solo-aire units.

Operating results of HUDSON Solo-aire units installed in oil, gas and chemical plants throughout the free world have led to continuing repeat installations.

For new process installations and for replacement of high maintenance water-cooled equipment, Solo-aires offer in most cases clear-cut advantages. Let HUDSON assist you in objective analyses of air versus water cooling.

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NEW HUDSON TUF-LITE FANS

After six years of development work and tests of trial field installations operating under wide ranges of conditions in cooling towers, finned tube coolers, and in highly corrosive chemical plant ventilating service, Hudson presents a new product—the TUF-LITE fan. The blades, cast in one seamless piece of fiber glass reinforced synthetic resin, are hollow, light and tough. TUF-LITE fans afford the following advantages over any other available type of fan:

SAFE: TUF-LITE blades being lightweight (about ¼ the weight of other blades with comparable capacity) and infrangible, eliminate the hazards to personnel and equipment existent through accidental throwing or disintegration of heavy metal, wood, or laminated blades while in service.

EFFICIENT: More air is moved at less horsepower because weight and finishing operations do not impose limitations on selections of best aerodynamic design; therefore nearly ideal airfoil cross sections, commercially attainable only in TUF-LITE blades, can be used. Blades will not sag or distort, and surfaces remain permanently smooth.

LOW MAINTENANCE: TUF-LITE blades are unaffected by corrosive, abrasive or impingement effects of hot saturated air, sand, rain, or hail, and have superior deterioration resistance to practically all corrosive vapors or liquids. Blade materials contain color pigment; no painting is necessary. Light weight reduces stress and maintenance on bearings, gears, drive shafts, and supports.

QUIET: The permanently smooth surfaces, very light weight, sustained perfect balance, and advanced aerodynamic design minimize noise.

EASE IN INSTALLATION: Light weight of blades and ingenious design of hub and blade coupling allows attachment of blades by one man using only small wrench. Coupling design assures uniformity of pitch of all blades, and as blades of same size are identical and interchangeable, perfect fan balance is preassured.

In replacement of present fans or in installations on new cooling equipment of any manufacture TAKE ADVANTAGE OF THE OUTSTANDING SUPERIORITY OF HUDSON TUF-LITE FANS.

Bulletin on TUF-LITE FANS
Available upon Request

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COOPER ALLOY VALVE BRIEFS

THE VALVE AND FITTINGS ANSWER CORNER

Send in your questions on stainless valves and fittings to Carl Tylka, Cooper Alloy Technical Service Director.

Q. *What is meant by "ferroxyl quality" in evaluation of a stainless casting?*

A. This means a superior surface quality free from pinholes, porosity, scale particles, iron film, grease, or other undesirable conditions, as is guaranteed by passing the ferroxyl test.

Q. *Will stainless steel of the 18-8 type corrode in a moist atmosphere?*

A. Not ordinarily, but it will in contact with graphite.

Q. *Can the use of stainless materials having different hardnesses be effective in preventing galling?*

A. Yes, providing the hardness differential amounts to 50 Brinell or more. Corrosion resistance of the hardened material is generally lowered, however, and trouble may ensue in severe service. Use of V2B alloy as the hardened medium will prevent galling and provide sufficient corrosion resistance.

Q. *Is 18-8s MO (316) better than 18-8s (304) for use in hot strong nitric acid?*

A. No, in this particular case 304 is better than 316.

Q. *Why is it that steel is resistant to 70% sulfuric acid, while stainless 304 is not?*

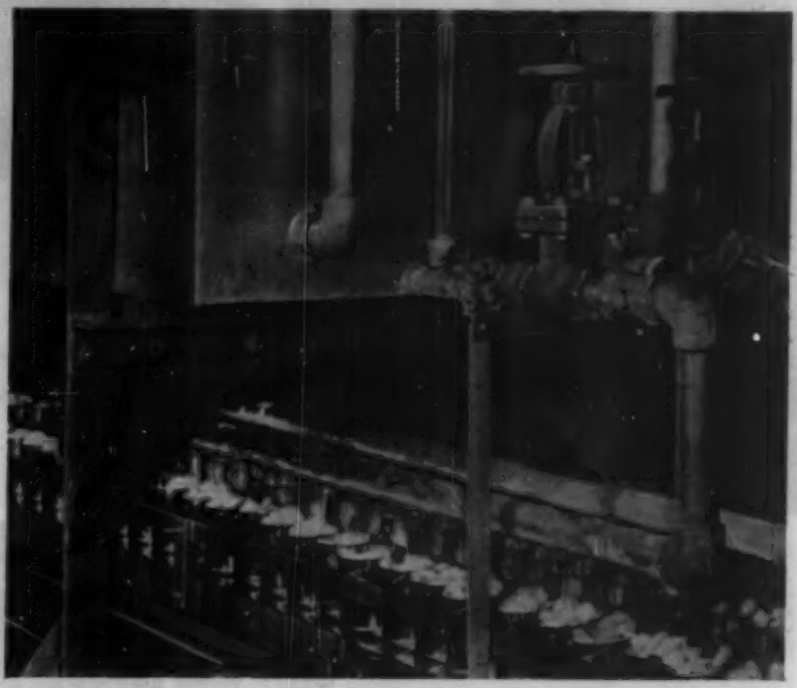
A. Because sulfuric acid forms an iron sulfate film on carbon steel which is insoluble in sulfuric acid of over 65% concentration, thus protecting the steel from further corrosion. This particular film does not form on stainless, which depends upon passivity for corrosion resistance. In 70% sulfuric acid passivity is lost and the stainless corrodes.

Q. *Is 316 alloy better than 304 for handling hot caustic solutions?*

A. No, 316 has no better resistance than 304 and FA-20. That is why Monel is recommended. In extremely severe cases use pure nickel.

Q. *What can I use where 316 is necessary for corrosion resistance, but fails through lack of resistance to accompanying abrasion or erosion?*

A. Cooper PH-55A alloy resists all corrosive media that can be handled by 316 (except very hot and strong nitric acid), and in addition is resistant to both abrasion and erosion.



How the Cooper Alloy Valve became a Giant—among Shrimps!

Cooper Alloy Valve Handles Hot Brine at Shrimp Canning Plant for Twelve Years Without Maintenance

It's not often that we get a chance to put a title as catchy as this on our valve success stories, but this story really rates it!

It all happened at the Robinson Canning Company in New Orleans, one of the world's largest canners of shrimp. They can as much as 100,000 lbs. of shrimp a day—three cans a second! And here's the problem: to the shrimp in each of these cans hot brine solution (180°F.) is added as a preservative—to the shrimps, that is, because brine is mightily corrosive to most valve materials.

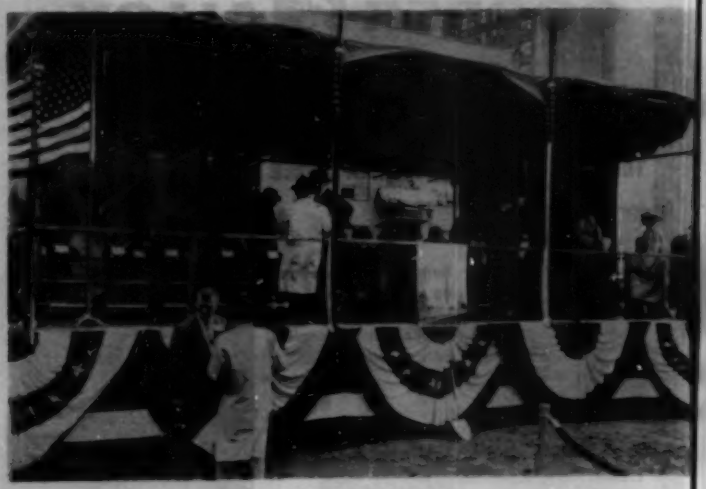
The master control valve for this gravity-feed brine-filling operation used to be a brass gate valve, but it couldn't stand the corrosion gaff. So, 12 years ago the Robinson people replaced it with a Cooper Alloy 1-in. Monel gate valve. (Vital statistics: OS&Y, 150-lb. service, bolted bonnet, screwed ends.)

And during the ensuing 12-year period, this Cooper Alloy valve has handled 2500 gallons of hot brine per day—without maintenance of any kind! Only very recently did it become necessary to replace a few non-Monel parts, such as handwheel, packing flange, and eyebolts.

As we said at the start of the story, that's a performance record that's a giant in any man's process! For more information on Cooper Alloy valves and their performance capabilities, write to Cooper Alloy Corporation, Hillside, N. J.

For more information, turn to Data Service card, circle No. 59

cep camera



Despite wind and rain, leading engineers gather on the rostrum to start the long awaited moment, the first step toward a permanent United Engineering Center.

Sunday panelists discuss where chemical engineering is heading. (L. to r.) Sid Kirkpatrick, Don Keyes, Jose Calva, Bob White, and Bill Licht.

Some highlights from St. Paul—One of the most successful meetings for A.I.Ch.E. to date.

Young chemical engineers engage in lively debate at the student session.

(Left) Tuesday Luncheon attracted large turnout to hear Dr. C. W. Mayo of the famed Mayo Clinic. (Above) Members of meeting committees gather with Mayo. (L. to r.) Russ Frederickson, Bill Podas, James Erwin, Mayo.

October 1 was the date! The event—Groundbreaking for the new United Engineering Center in New York.

A.I.Ch.E. president Katz greets former President Hoover after the formal ceremonies.

Former President Hoover shares the honors with young Jerry Fujimoto, Hawaiian freshman engineering student at Rensselaer.

UN building overlooks part of large turnout that braved the rain for historic occasion.

President Hoover leaves rostrum with the UN building in the background.

When and how to quit a job

When you change jobs, be sure to do everything in your power to leave your old employer with tears in *his* eyes, said Thomas Birch, Hergenrather Associates, West Coast executive search firm, to the *Southern California Section's* (*R. D. Sheeline*) August meeting. The job of changing jobs is a serious one and may mean the difference between success and failure in your career.

The first consideration is "when". Timing is a vital factor. When you decide to change your job, it should be for one of only eight logical reasons:

1. You are unhappy, frustrated, and not making satisfactory progress. (Be sure this is not the reason for every job change!)

2. You are not in the right job, in the right field, or with the right company.

3. You are blocked from successful advancement. (Be sure there is an effective road of advancement for you.)

4. Health or climatic conditions.

5. Wife problems. If factors about your job makes your wife unhappy, you will not be effective in your job.

6. Your company is failing and you've done your best to prevent it. (Don't stay on to the end once you are convinced failure will occur.)

7. If you need more money. (But be sure you're worth more.)

8. When you are merged or acquired out of a job. (But don't run at the first rumor.)

The "How" of changing a job is as important as making the "when" decision. You must know what road you want to travel. Don't let destiny and fate plan your career. Always do your very best in any job you hold.

If a job comes your way investigate the company, the personalities of its people, and talk to people who know the company.

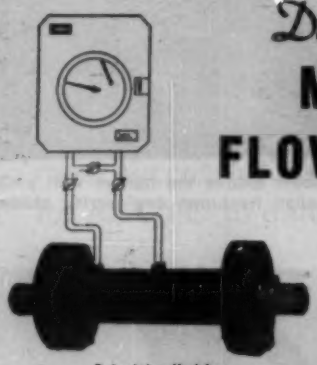
While you are looking, advertise discreetly in your profession's publications, the Wall Street Journal and by telling everyone you can trust. Prepare a good resumé, but keep it brief. *Indicate your job objective*, as this helps prospective employers in properly placing you.

To win in making a job change, set goals for yourself with respect to salary and professional progress. Age and salary ranges for the top ten percent of executives are listed below as guides:

Age	Salary
27-30	$9 - 12,000
31-35	12 - 18,000
36-40	18 - 25,000
41-45	20 - 30,000
46-50	23 - 35,000
50 and over	28 - 50,000

Follow these goals and don't change them except for very sound reasons. Make your mark in one field before you hop to another. Learn as much as you can about other jobs in your

continued on page 164



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Metering and controlling mass flow rate of gases is easy and simple with the NIL primary element.

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- Convert your present system to mass flow metering or controlling by substituting the NIL element for the orifice or venturi.
- Easy installation in line with no offset, the element is as easy to install as a valve.
- Rugged and trouble free, the element has no rotating parts.
- Automatic, the density compensation is made by a stainless steel bellows and requires no electrical or other auxiliary power.
- Complete metering or controlling system or primary element alone is available.

WRITE FOR BULLETIN 178

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SPIRAL CONDENSERS ON TOP

Our new Series "G" condensers are designed for installation as the top section of a column or for direct connection to the vapor outlet nozzle of a vessel.

Economy is obvious in the elimination of elaborate supporting structures, large diameter vapor lines and other auxiliaries essential to conventional designs.

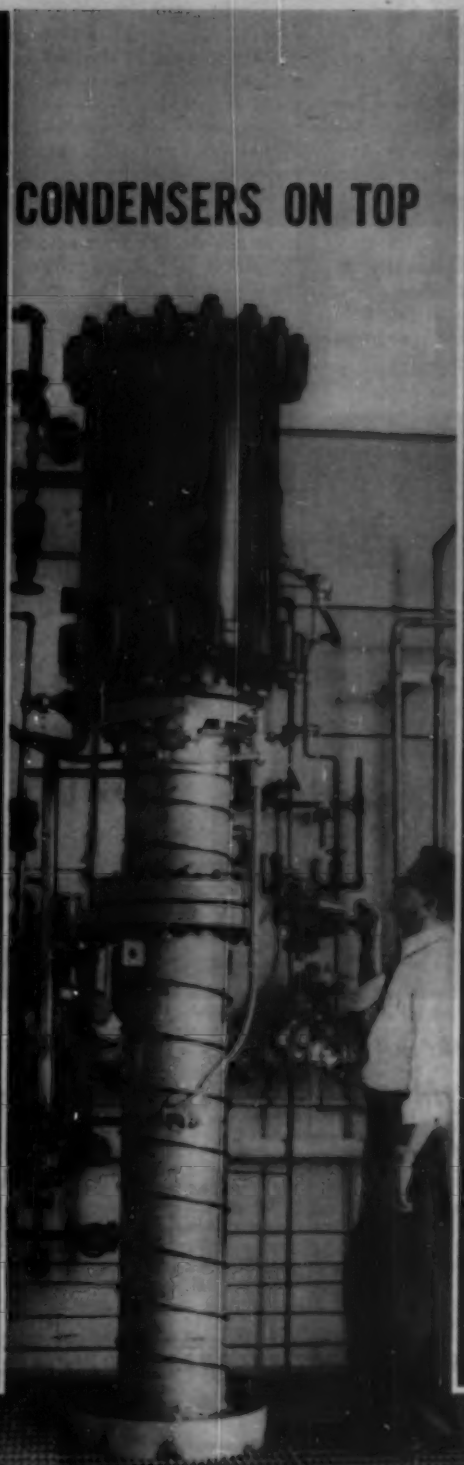
None of the exclusive features of the Spiral condenser have been sacrificed for this direct mounting arrangement. The vapor path can be full counter current spiral flow, combined cross flow-spiral flow or full cross flow. Any combination for maximum or minimum cooling of condensate and noncondensables can be obtained in the in-built after-cooling zone.

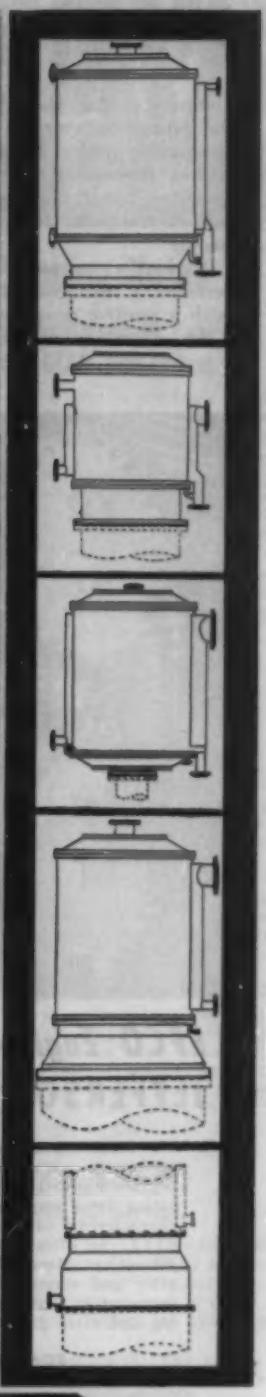
The Spiral condenser is unequaled for stripping out soluble gases. The rapid and complete separation of condensate from fixed gases prevents partial re-absorption, and separate outlets are provided for the condensate and the noncondensables.

The Spiral is furnished for either total, partial, reflux, vent or knock-down condensing services in sizes from 15 sq. ft. to 1600 sq. ft. and for design pressures up to 150 p.s.i.g. Large volume condensate retention capacity can be incorporated when desired.

Spirals are fabricated in any material that can be cold formed and welded to ASME Code requirements.

Write for full particulars.





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local sections

from page 162

company so that when the time comes for promotion you are ready. Most companies prefer to promote from within. Remember that at the higher executive levels, one must be able to sell, control costs, and get along with people.

Choose a company generally interested in management development with a positive program in this field. Take advantage of these programs.

Change your job when you—and your family—decide a change is important to your career; set goals and work like the "very dickens" to achieve them as quickly as possible.

Engineers who do change jobs should be cautious in using special knowledge gained under the former employer, John Revis told the **Southern California Section** in June. If they have any doubt about who owns this knowledge, a qualified attorney should be consulted prior to applying it in the second position. Revis is former head of the Legal Department, Ralph M. Parsons, and present chief counsel for Paul Hardeman Co.

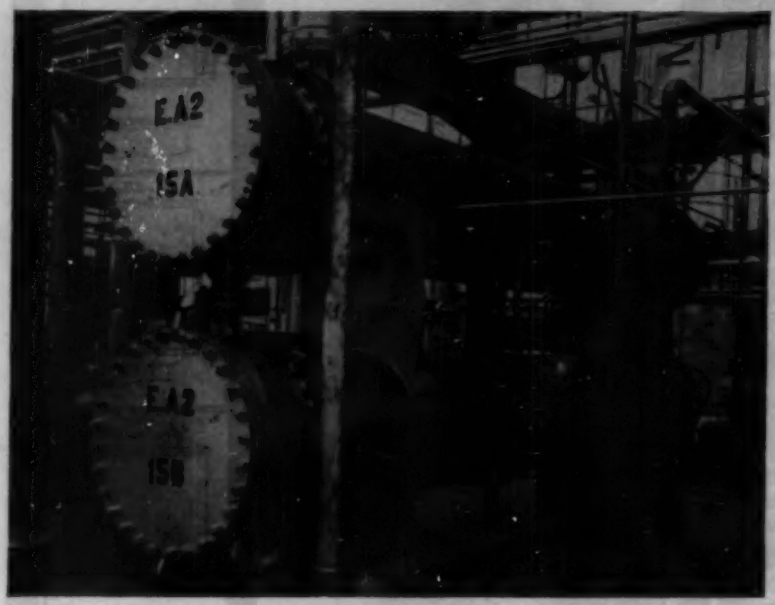
This course, as a matter of self-protection, becomes necessary in view of recent court decisions restricting the use of certain types of knowledge. Courts have ruled that any special knowledge, tools, methods of manufacture, etc., developed by a company's employees, are the property of the company. Therefore, any individual who employs these trade secrets or customer lists to the competitive advantage of the second company may be liable. In addition, the second company may also be liable if it knowingly uses such information.

Solids conveying in the process industries was a subject well covered at the annual meeting and panel symposium of the **Western Massachussets Section** *(A. W. Andrews, Jr.)*.

Mechanical Systems for Raw Material and In-process Conveying was discussed by John Fischer, chief materials handling engineer at Sprout Waldron, Muncy, Penna. Another panel, Pneumatic Systems for Raw Material and In-Process Conveying, was led by John Russell, the Dracco Division, Fuller Corp., Long Island City, N.Y. Warren Geigel, staff engineer, Plastics Division at the Monsanto Springfield plant, chaired the third panel. His session covered the topic, Systems for Handling and Shipping Finished Goods.

Also meeting

Should engineers be organized was debated pro and con at the September meeting of the **Western New York Section** *(Reed E. Garver)*. Ray Fremed, McGraw Hill Publishing, Earl Shilt, Zaremba Co., and Richard Woll, Westinghouse Engineers Association, Westinghouse Electric, were the panelists. Joseph Shister, University of Buffalo, moderated . . . The **Charleston Section** *(G. O. Walker)* toured Kaiser Aluminum Plant at Ravenswood in September . . . The Section is planning to continue its cooperation with the Charleston Section of ACS in the scholarship fund . . . Some particularly promising areas of research were touched upon at the **New York Section** meeting *(C. Labine)* in September. Hugh Hurlburt, director of physical research, American Cyanamid, Stanford, Conn. was the speaker . . . a general description of Butyl Polymerization production, facilities was given to the **Pittsburgh Section** *(G. J. Haddad)* October meeting. Reaction conditions and a broad description of the properties of the polymer and the manner in which these properties have been used to advantage were included.



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Jefferson Chemical Company, Inc., is one among many process equipment users who profit from the economy provided by EFCO engineering efficiency. Years of experience in engineering and fabricating heat exchangers for the wide temperature/pressure ranges characteristic of ethylene and other manufacturing processes enable EFCO to offer service-proved engineering design and guaranteed job-ratings. Recognized specialists in handling all grades of carbon, alloy and stainless steels, and nickel, aluminum, and special low-temperature materials, EFCO provides technical service before, during and after installation.

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service-proved engineering design
guaranteed job-ratings
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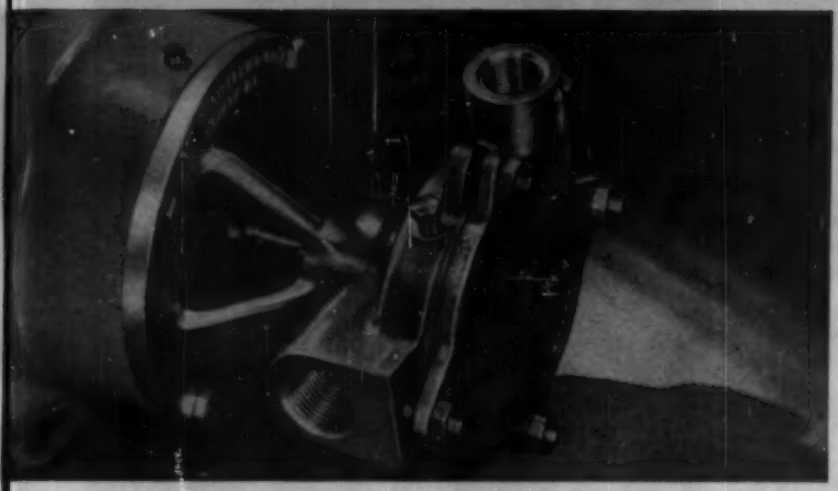
ECO ENGINEERING NEWS

VOL. 1, NO. 5

the big name in small pumps for the process industries



Close-coupled motor-mounted CENTRI-CHEM Pump.

Standard, Stock Centrifugal Pumps Handle Wide Range of Corrosive Media

Eco CENTRI-CHEM* Pumps feature Type 20 stainless steel throughout—casings, shafts and impellers—meeting a wide range of corrosion services.

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These pumps were designed to meet the standardization programs of major multiplant, chemical companies, but they offer equal advantages and economies to medium sized and small plant operators, requiring small centrifugals with capacities up to 40 g.p.m.

Manufactured on a precision, mass-production basis (instead of being "custom-built" as are most other chemical-resistant pumps of this type), costs and prices are kept low. Every part is interchangeable. Pumps and repair parts are stocked for immediate delivery, by air if required for emergency needs, guaranteeing the very miminum down-time.

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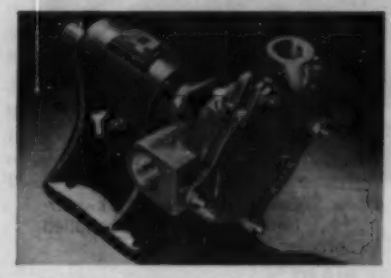
In every centrifugal pump, the shaft seal is usually its weakest point. The exclusive design mechanical seal used in the CENTRI-CHEM Pump has proven leak-proof under the most severe conditions. It also has handled sticky fluids for many months where other seals have gummed up and failed in minutes. Seal components to meet various exposures, include TEFLON† and ceramic, carbon and ceramic, and carbon and Type 20 stainless or Stellite.* All seal components are interchangeable.

New Bulletin Just Released

Write for your copy of Bulletin CT-859 which describes these remarkable pumps in detail.



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Pumping Notes

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New Phenolic Plastic Gears Resist Chemicals—Wear Longer

Advancement in phenolic resin plastics technology has made great strides in recent years. Results range all the way from ultra-high temperature resisting materials suitable for rocket nose cones, to new materials which are not attacked by such widely used acids as Sulphuric, Hydrochloric and Hydrofluoric, in all concentrations and combinations. These resins are unaffected dimensionally or chemically with exposure to these acids and numerous other corrosive and problem media.

Gears generated from this phenolic plastic are now recommended for long sustained, heavy duty service in Eco GEARCHEM Pumps for such chemicals, as they have proven mechanically stronger and show minimum wear. They may be used in pairs or as idler gears in combination with metallic gears.

Hastelloy B Pumps for Hot HCl Service

Eco GEARCHEM Pumps in Hastelloy B are expressly produced for HCl service in advanced temperature ranges (up to 160°F). Both the 3 g.p.m. and 10 g.p.m. sizes of GEARCHEM Pumps are available in this alloy.

Regularly supplied with TEFLON or carbon bearings and TEFLON, phenolic or Hastelloy B gears, and with grease-sealed extended stuffing box.

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The process design engineer

In recent years the process design engineer has become identified as an individual performing a specific type of engineering work.

- **The opportunities and responsibilities of the field.**
- **Scope and proper placement of process design engineers in an industrial organization.**

E. E. Ludwig, *Dow Chemical Co., Freeport, Texas*

1. First step in the process design approach consists of hours of problem analysis.

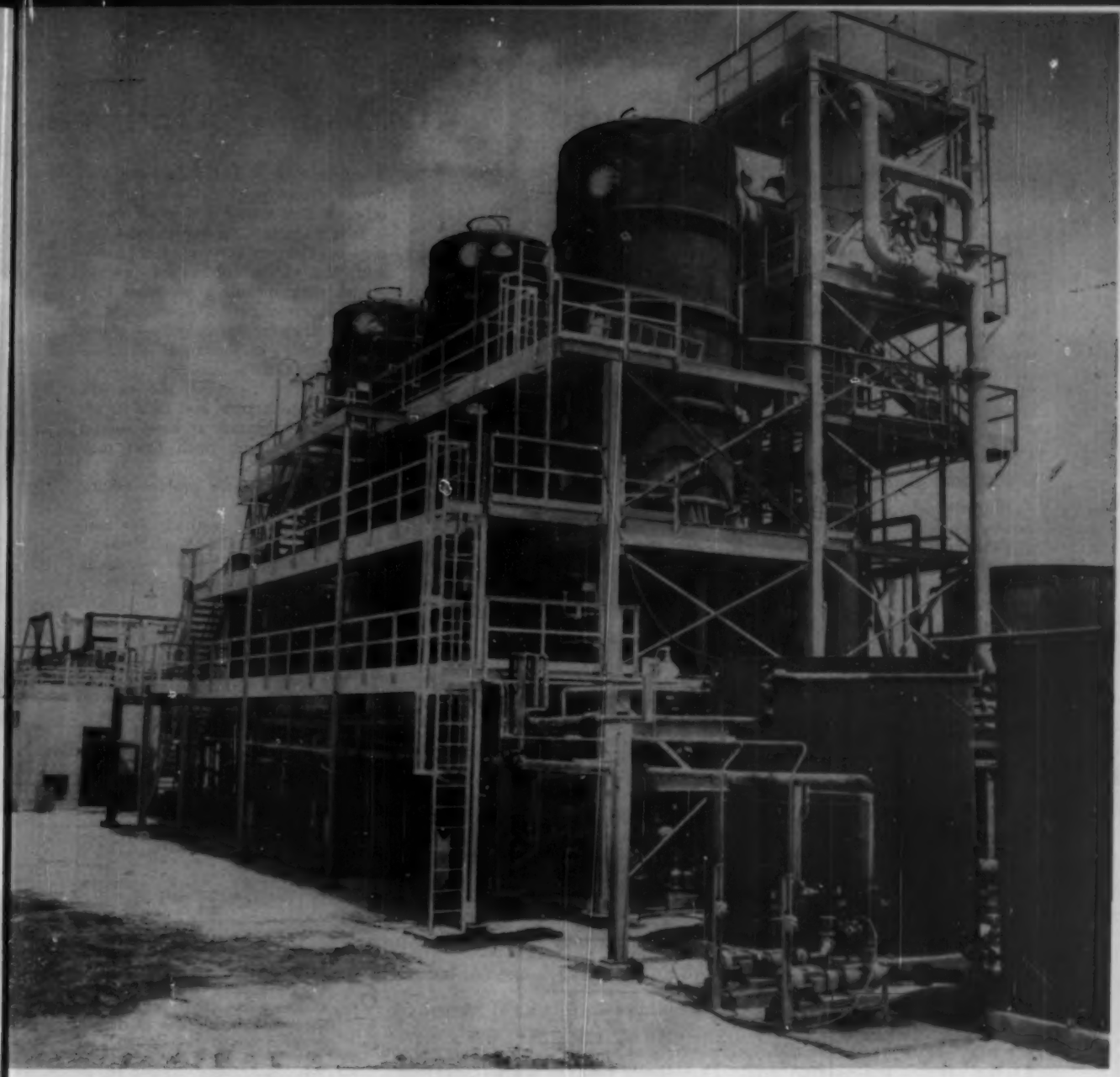
In general, the process design engineer is concerned with developing the process flow cycle, and the economic sizing, selection, and specification of the individual items of equipment required for a process industry. The extent of his participation in closely related engineering areas depends on the company organization. It is important that process work be summarized for use by others. Summaries usually take the form of specification sheets and flow sheets in order that the information developed may be incorporated into the engineering of the plant. An integral part of the process specifications is the mechanical interpretation, that is, the incorporation of mechanical details in the equipment which will insure the functioning of the process in accord-

continued on page 168

2. The Process Design Engineer works closely with draftsman in flow sheet preparation.

3. Problem design and specification sheet preparation is an important phase of the preliminary operations.

4. Electronic computers perform many tasks in applied process design.



Giant Buflovak evaporator produces 50% and 73% caustic for Jefferson Chemical

At Port Neches, Texas, this 188-ton evaporator for electrolytic cell liquor goes on stream. It's a triple effect operation—concentrating to 50%, recovering the salt, cooling the caustic to remove the salt, and then concentrating as much as half the caustic to 73%.

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Buflovak installations all over the world total 3,000 tons of caustic production per day on a 100% NaOH basis. Units are custom designed and built in single, double, and triple effects, and range in capacity from 10 to 880 tons per day. Buflovak's complete line of evaporators provides cost cutting answers to a wide range of processes.

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from page 166

ance with the flow cycle. Thus, the process design engineer must often ride a pseudo-chemical-mechanical "fence." For example, a separator without the necessary baffles may not function as an efficient unit. The process design engineer must be able to visualize the performance of each unit and design, and to specify in accordance with practical understanding and available performance data for such equipment. Thus, a process design engineer is a unique mixture that includes many facets of engineering.

Educational background

The minimum curriculum requirements are sometimes insufficient to produce a strong and practical process design engineer. In addition to the usual accredited college courses for the degree, some suggestions to strengthen the potential process design engineer are:

- Advanced calculus plus statistics;
- Kinetics, advanced thermodynamics;
- Metallurgy and machine design;
- Fundamentals of electrical engineering;
- Report writing, public speaking, business practices, and business law.

In general, the process design engineer must be well founded in the

5. The Process Design Engineer must keep up-to-date by reading technical books and journals.

fundamentals of mathematics, physics, chemistry, and engineering. But this is not enough—a good engineer who expects to progress must be practical and must also be able to express himself well. This is particularly true of design engineers, where the details and results of their efforts are to be found in calculations and similar work. They must be able to bring the key points of their work to the surface for others to understand and to act upon.

It is important for the process design engineer to keep up technically with the various phases of process engineering, including processes and their improvement. This requires a steady program of voluntary study and reading of technical journals, new books, etc.

An interest in using the newest methods, techniques, and tools in accomplishing the task at hand should be second nature. Such tools may include:

- Nomographs for problem shortcuts;
- Standardized methods for routine or "standard" problems;
- Electronic computers to aid in better analysis of problem variables.

6. The Process Design Engineer works with other engineering specialists in the use of models in plant layout and design.

It takes time to gain experience. However, a good engineer should recognize that experience must be planned. The lesson to learn is to be observant, eager, and interested in new things, problems, and associations.

Broadly, we can say that the work of the process design engineer is applied to chemical engineering unit operations for economical new plant design, economical maintenance, trouble shooting, or for research and production development.

To understand a problem or process, it is most convenient to plan with a description of the flow cycle. This is usually represented by a flow sheet

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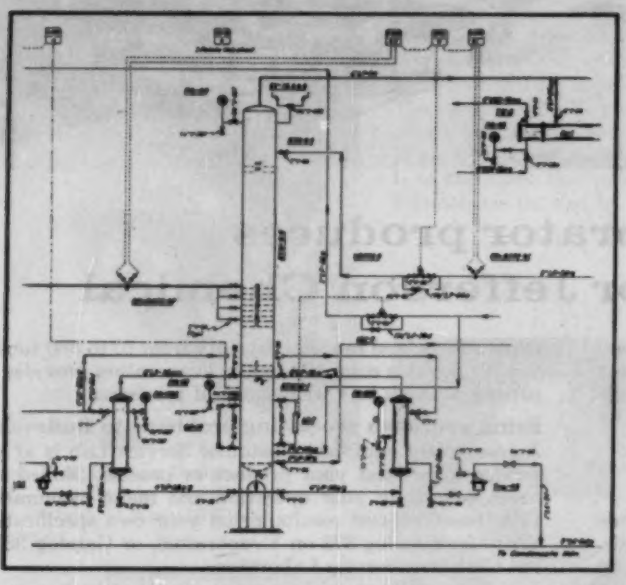

Figure A. By using a flow sheet the process engineer establishes the sequence of equipment and flow.

For more information, circle No. 34

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Ammonia Plant—Designed, Engineered and Constructed by Lummus—Feeds Natural Gas or Butane

The St. Paul Ammonia Products, Inc. plant at Pine Bend, Minnesota has been operating continuously at rates above the design capacity of 200 tons per day of ammonia. Lummus' policy of close cooperation with the client at every stage was followed at St. Paul Ammonia. Lummus' extensive experience in plant design and construction have been effectively combined with the experience in plant operation of St. Paul Ammonia's capable staff in order to achieve a successful project.

In addition to producing anhydrous ammonia and ammonium nitrate solutions for the fertilizer industry, St. Paul also produces anhydrous ammonia meeting industrial specifications.

The Texaco Synthesis Gas Generation Process is employed to produce hydrogen for ammonia synthesis. Natural gas direct from the pipeline is normally used as the raw material. However, during the cold Minnesota winters the supply of natural gas is subject to interruption when preference is given to household users. The plant is designed so that at these times butane is used as the raw material.

The large compressors are gas-engine driven and use natural gas fuel except during the winter months, when propane from storage tanks is employed. The Lummus design fits the plant to the needs of the area and permits this sort of flexible operation.

This plant utilizes a hot potassium carbonate system for removal of CO_2, which helps reduce production costs.

Lummus acted as general contractors for the entire project which includes ammonia synthesis, nitric acid, and ammonium nitrate solutions units, and offsite facilities including utilities, tankage and product shipping.

Lummus has experience in design and operation of ammonia plants utilizing natural gas, heavy fuel oil, butane, and waste chlorine cell hydrogen. Capacities of Lummus built ammonia plants range from 60 to 300 tons per day.

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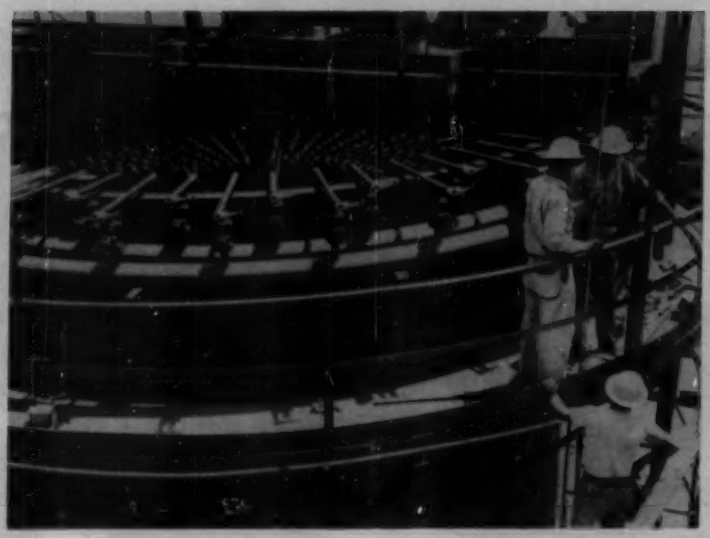

7. Design becomes reality as main pieces of process equipment are assembled.

Process design engineer

from page 168

or diagram, Figure A. Here, the sequence of the equipment and its flow relationship in the process is established and pinpointed by the process design engineer. With the flow cycle as the reference base, the necessary material and heat balances can be made. Then, with these as base points, the individual designs of the equipment needed for the process cycle can proceed. Next, summaries of the calculations and specifications for the particular item are set forth by the process specification sheet. Step by step, process area by process area, the various distillation columns, absorber columns, condensers, reboilers, coolers, pumps, compressors, and other equipment are calculated and specified for performance and engineering details, including materials of construction.

Economics

Practically every process cycle involves items requiring economic consideration. This includes economic comparison of various processes to make the same product, various schemes to obtain the necessary process refrigeration, schemes of heat conservation, reciprocating versus centrifugal compression, drivers for large blowers, compressors, etc. All of this requires attention to the capital cost of the equipment, auxiliaries, and associated utility equipment, as well as to the cost of operating labor, raw materials and utilities. This is one of the most interesting as well as important phases of the process engineer's work.

Company organization

Engineering companies, and engi-

continued on page 172

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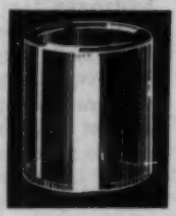

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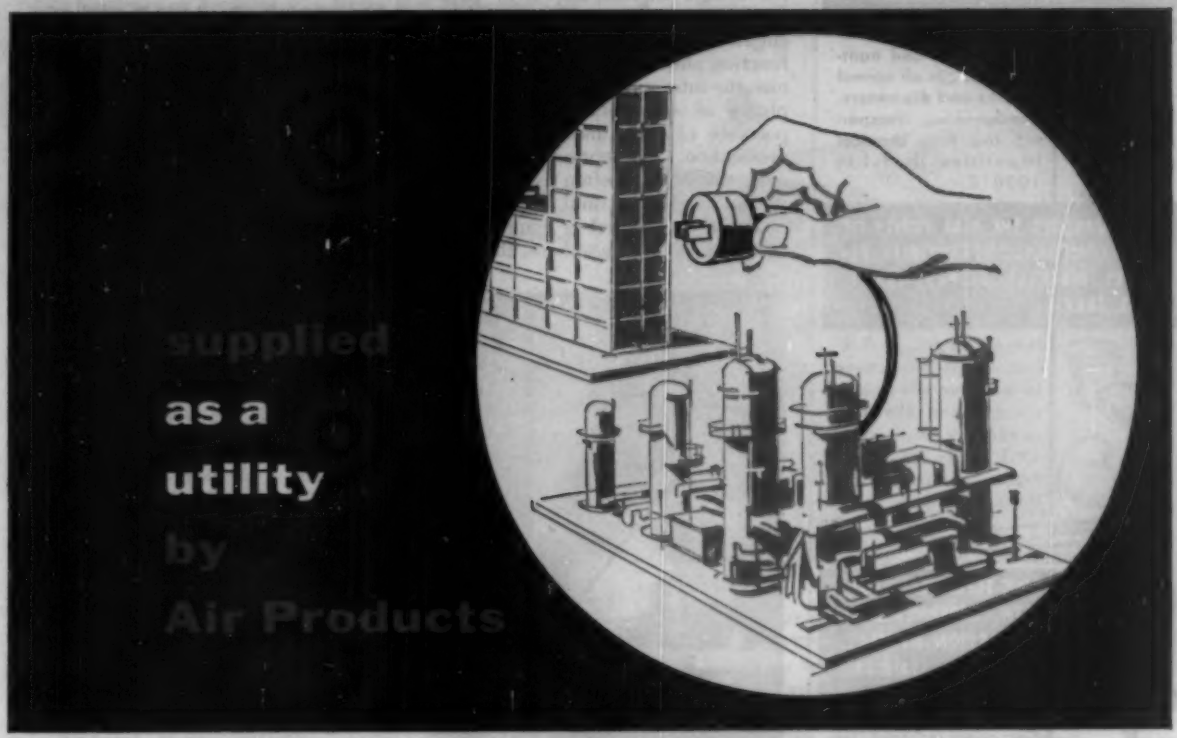

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Process design engineer

from page 170

neering departments in process companies, usually delegate contact responsibility to one individual designated as the project engineer. For the intent and purpose of the operation a team is developed around this individual—a team composed of process design, mechanical, civil, structural, electrical, instrument, and utility engineers. In order for this team to function effectively, each must recognize the inter-relationship of the other phases of engineering, and the importance of close and detailed communication. For optimum effectiveness, this team is often assigned to a special workroom until the planning phase of the project is completed.

In this team atmosphere, the process design engineer contributes his part.

8. A towering column is hoisted into place as the plant takes shape.

He determines process job requirements, and secures a sufficient number of process design engineers to work with him in preparing process work.

Under the direction of the team, he guides the preparation of a flow sheet by an engineering draftsman.

Concurrently, he prepares the material and heat balances for the process, and carries through the calculations for distillation columns, heat exchangers, pumps, compressors, piping, etc.

He forwards specification sheets for the equipment to the project engineer and the project team. (Some speci-

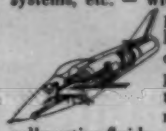
continued on page 174

a filter man's thinking

FORESIGHT: Developing the solution before the problem comes up

It takes a long time to translate the need for a new aircraft into an actual piece of flightworthy hardware. It can take forever — if its special operating requirements can't be met by known materials and components. Few jets would be in the air today if certain industrials — like Purolator — hadn't recognized that difficult operating conditions had to be anticipated long in advance.

A modern aircraft has a maze of circulatory systems: fuel, air, lubrication, pneumatic, and hydraulic lines . . . instrument systems, etc. — with filters playing an important role in each. In high performance jets extremes of temperature, pressure, flow and structural strain . . . and the need to handle chemically-active fluids . . . preclude the use of the kinds of filters which had proved adequate for older aircraft. To fill the gap, our engineers some years ago developed Purolator's famous porous metal filter medium. This type of filter has since been brought to a high degree of efficiency.



Purolator makes these media by a unique method of fusing metal powders of controlled particle size to obtain the desired porosity. The metals used are matched to specific service requirements — and include all grades of stainless steel, nickel, monel, Inconel, Hastelloy, bronze, gold, silver, etc.

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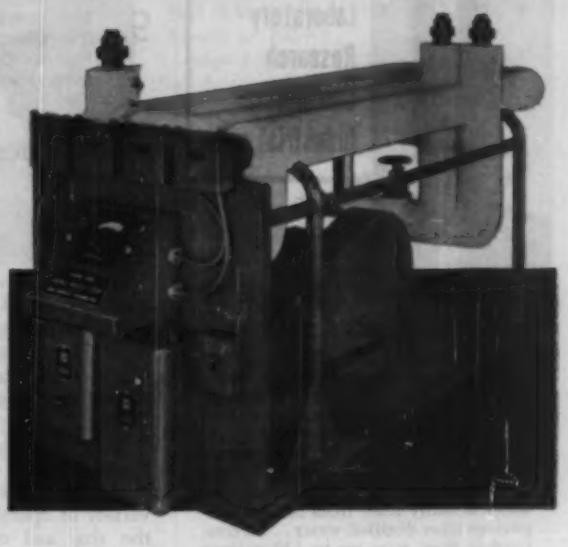

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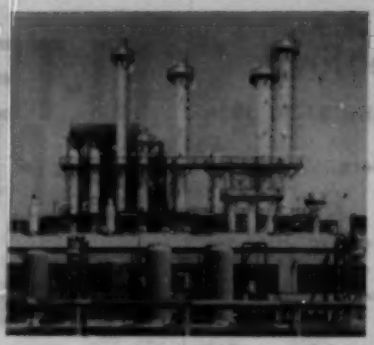


9. The completed plant embodies the coordinated efforts of the Process Design Engineer and his associates.

Process design engineer

from page 172

fications may be directed to the purchasing department for inquiry).

He contributes and checks process-related parts of the job-line schedule sheets which tie the flow sheet to piping requirements.

He contributes information for decisions by other engineering operations.

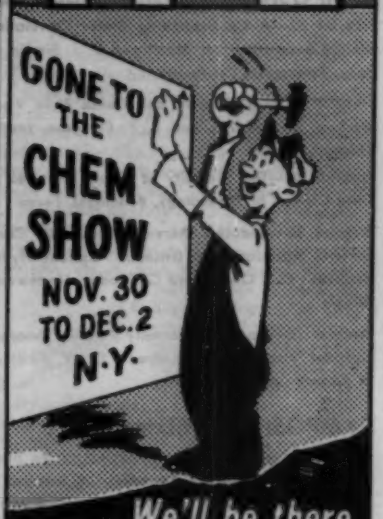
These are the key operations and responsibilities of the process design engineer. At each step, there is a variety of operations, depending upon the size and type of project being considered. However, it is typical for the process design engineer to follow and be a part of the project to its engineering completion, and often on into the construction, start-up, and trouble-shooting stages.

Materials, Plant layout

Drawing up of proper specifications requires a broad knowledge of old and new materials of construction such as metals, plastic coatings, rubber coatings and linings, acid-proof and alkali-proof cements, ceramics, etc.

Plant layout as an over-all area, and as individual units in the area, must be properly planned. Planning requires a knowledge of essentially all fields of engineering, as well as production operations and specialized parts of the construction and erection operations. In order to start planning for any project, it is necessary to know what is required for the process operation. This includes the process cycle and the size and specifications of the equipment. Here, the process design engineer must do his planning, thinking, and calculating before any specific planning of the over-all process-related parts of the job can be started.

IPE



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people in management and technology

Sage named 1959 winner of Walker Award

Bruce H. Sage, a member of the chemical engineering faculty at the California Institute of Technology, ordinance expert and author, has been named recipient of the 1959 William H. Walker Award of A.I.Ch.E. The Award, given annually to a member of A.I.Ch.E., is awarded for an outstanding contribution to chemical engineering literature. It will be presented during the 52nd Annual Meeting of the Institute at San Francisco December 6-9. Its purpose is to encourage excellence in contributions to chemical engineering literature. The Award has been made each year since 1936 to some of the nation's outstanding chemical engineers.

Sage has been on the research and teaching staff of Caltech since 1935. He was named professor of chemical engineering in 1944. In 1945 he was

made head of the Explosives Department, Naval Ordinance Test Station, Inyokern, California and in 1949 he became associate director of engineering, then senior consultant of the Test Station. He is co-author of some 200 scientific publications and five books on chemical engineering.

In 1948 he received the Medal of Merit for ordinance development work during World War II. In 1949 he received the Precision Scientific Company Award in Petroleum Chemistry from ACS. The AIME presented him with the Anthony F. Lucas Gold Medal in 1954. He also received the 1956 Hickman Award of the American Rocket Society and the U.S. Naval Test Station's L.T.E. Thompson Award in 1957.

Sage received a master of science in chemical engineering and a doctorate in mechanical engineering from Caltech in 1931 and 1934, respectively. In 1953 he received an honorary degree of doctor of engineering from New Mexico A. & M.

Hiram Leroy Smith, Jr. has been appointed chief engineer, Chemical Division, at Bowen Corp. Smith recently returned from France, where he was project engineer for Stone and Webster on a chemi-groundwood pulp mill at Pas de Calais.

continued on page 176

BIG NAMES

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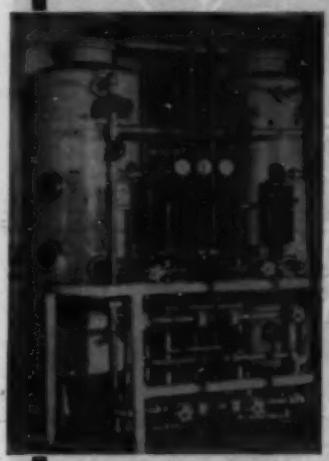

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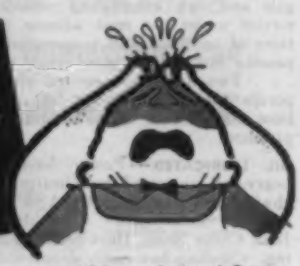

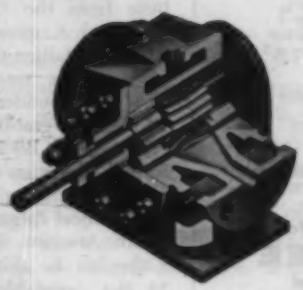

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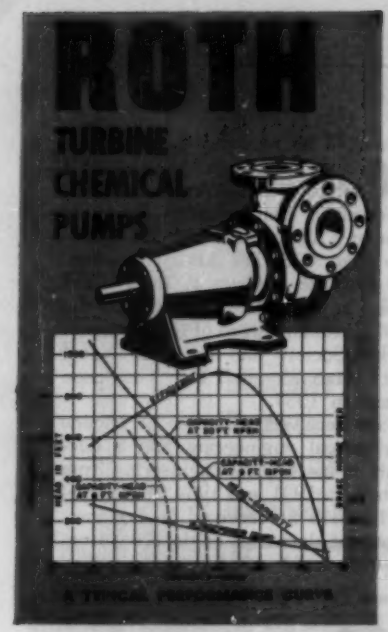

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For more information, circle No. 69

people

from page 175

His varied background includes work on chemical, oil, and salt manufacturing projects; vapor compression process work regarding the vaporation of sulphite waste liquor from paper mills; and basic work on special evaporators for submarines. Smith has a patent pending on his Density Controller for Light Hydrocarbon Fractions.

Donald B. Keyes has been appointed a visiting professor of Chemical Engineering at Stevens Institute of Technology, Hoboken, New Jersey. He is teaching the course Chemical Process Design and Evaluation in the fall term.

Max S. Peters received the 1959 George Westinghouse Award of the American Society for Engineering Education. Peters is head of the Department of Chemical Engineering at the University of Illinois, and is active in directing both graduate and undergraduate research work. In addition to publishing twenty scientific papers, he has written two books, *Elementary Chemical Engineering*, and *Plant Designed Economics for Chemical Engineers*. His own research work is in the field of kinetics and mechanisms of chemical reactions.

As head of the division of chemical engineering at the college, Peters revised the curriculum. It now gives students flexibility in planned substitution of courses such as advanced mathematics, physics, and chemistry, for more conventional courses.

Peters is a member of the Program Committee, and the Professional Development Committee of A.I.Ch.E.

Guy Jorquera recently received a tribute from the Chilean Institute of Chemical Engineers in the form of a gold medallion mounted on a leather plaque. The medallion is inscribed "To Our Founder and first president 1933—with gratitude." Jorquera, after receiving his BS in Chile, finished his formal education in the United States. He established the first Department of Chemical Engineering in Columbia, South America. During 5½ years in Columbia, he also acted as consultant to the vegetable oil and chemical fertilizer industries. He is now with the Lummus Company, New York City, in the Process Department.

Leon S. Kowalczk has been named chairman of the Department of Chemical Engineering at the University of

continued on page 178

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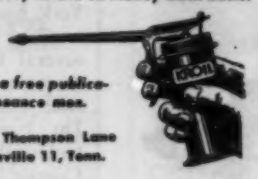

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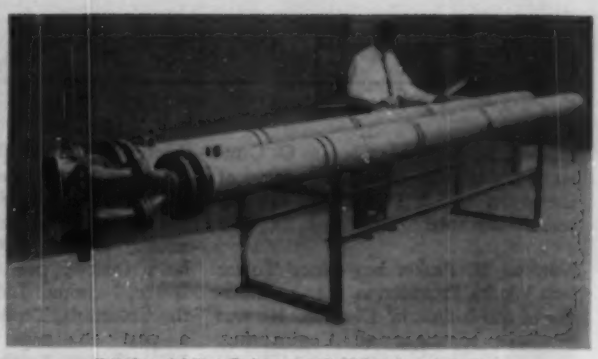

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from page 176

Detroit. He succeeds **Charles G. Duncombe,** who will continue to serve at the University as Director of the Research Institute.

Norman H. Parker has joined Tower Iron Works, Providence, R.I., as manager of the Industrial Division. He was formerly manager of Engineering, Turbo-Mixer Division, at General American Transportation.

Allen G. Erdman promoted to plant manager at Monsanto, Springfield, Massachusetts. Erdman has been with the company since joining the Research Department in 1939, and held various positions at the Oak Ridge National Laboratories and at the Columbia, Tennessee, plant. He is a past chairman of the Western Massachusetts Section of the Institute.

The present chairman of the local section, **Alfred W. Andrews,** has also taken on added responsibilities at Monsanto. Assistant director of engineering for the Plastics Division at Springfield, Andrews will also handle overall departmental engineering relationships, as well as development, planning, and plastics engineering groups.

Also promoted is **Robert K. Dimmitt,** who becomes assistant director of engineering, taking over Andrews' work.

Albert H. Cooper has been named head of the new University of Connecticut Department of Chemical Engineering. Cooper, formerly with the Chemical Engineering Department at Pratt Institute in Brooklyn, New York, has also held posts as a working engineer and as an executive with several firms. Included are positions as process engineer with US Industrial Chemical, research engineer at Du Pont, and vice president and technical director, Chemecon Corp. Cooper is author of 25 technical articles, and has five United States patents pending. He is currently working on two textbooks in the field.

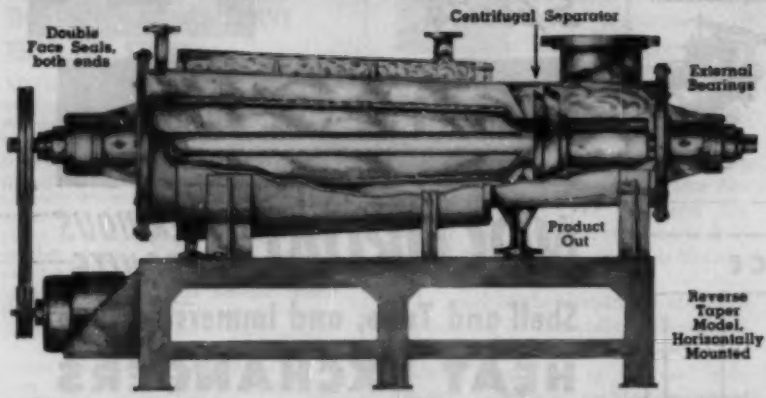
Saul Ricklin moves up to the post of vice president in charge of development at Dixon Corp, Bristol, R.I. Formerly president of Ricklin Associates, he recently joined the firm as director of development.

Jose A. Samaniego has been appointed general chairman of the 1960 Bay Area Committee for Engineers' Week. Samaniego, who works at Shell Development's Emeryville, California, Research Center, also served the Committee as general co-chairman in 1957 and 1959. A past chairman of the local A.I.Ch.E. Section, in 1950 he edited the publication, San Francisco Engineer.

Theme this year of Engineer's Week is: Engineering's Great Challenge—The 1960's.

Harry B. McClure, vice president, Union Carbide, has been named to receive the Chemical Industry Medal of the American Section, Society of Chemical Industry. The Medal has been awarded to McClure in recognition of his outstanding contributions to the development and progress of the chemical industry. He has spent over 30 years in the industry, during which time he has been concerned not only with the development of chemicals, but also in finding indus-

Kontro



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people

trial uses for them. The author of many technical papers and articles, McClure was awarded an honorary degree of doctor of science by Morris Harvey College in 1948. He also received the first honor award of the Commercial Chemical Development Association for valuable service to the chemical industry. He has been associated with Union Carbide since the beginning of his career in 1928.

J. N. Stone transferred to the Research and Development Division of Champion Paper and Fibre at Hamilton, Ohio. His work will consist mostly of development and market research in the chemical products field.

Edwin H. Young has been promoted

to professor of Chemical and Metallurgical Engineering at the University of Michigan. A staff member at the University for twelve years, Young has been for several years director of the Wolverine Tube Finned-tube Heat Transfer Project in the University Research Institute.

Charles S. Keevil has joined the Helen Edwards & Staff Agency in Los Angeles. He is a specialist in the placement of scientific and engineering personnel.

Frank C. Haas heads up the new Chemical Division at the Lee Wilson Engineering Company in Cleveland. Haas was formerly vice president and director, Archer - Daniels - Midland Company.

Harry G. Simmerman has joined the chemical engineering staff of General Mills Central Research Laboratories, Minneapolis, Minnesota.

George T. Atkins has been retained by Foster Wheeler as a full time consultant in petroleum refining and petrochemical processing. Atkins is widely known in the field of process design of distillation, heat transfer, fluid catalytic cracking, extractive distillation and waste heat recovery facilities.

Grant E. Stueber has been named manager of chemical process development at B. F. Goodrich Chemical Development Center, Avon Lake, Ohio. Stueber was formerly a development supervisor at the installation.

Lester B. Cundiff has been named senior process engineer in the Polyolefin Department, American Viscose Research and Development Division.

continued on page 180

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people

from page 179

Ralph Knight has been appointed a vice president of U.S. Industrial Chemicals (National Distillers). Knight will continue to direct the Polymer Service Laboratory, as well as working on U.S.I.'s polyolefin development program. Knight, since joining the company six years ago, has served in the capacity of polyethylene manager, both in production and planning.

J. H. Perkins, Jr. moves up to the position of project engineer in Diamond Alkali's Process Development Section. His work will be in the high pressure laboratory of the Research Department.

Joyce E. Hooper has joined Ethyl Corp, Baton Rouge, as an engineering assistant in the Research and Development Department.

C. C. Williams, III has been appointed supervisor at Shell Development's Emeryville Research Center. He is in the Oil Process Engineering Department.

Leland W. Milligan, Jr. joined U.S. Borax Research (U.S. Borax & Chemical) as research engineer. Milligan has been assigned to the chemical engineering research department, with headquarters at Boron, California. He was previously with the U.S. Bureau of Mines, Louisiana, Mo., and the Midwest Research Institute.

J. E. Cauley, Jr. promoted to senior chemical engineer in Humble Oil & Refining's Baytown, Texas, refinery. He is engaged in the design of facilities to increase production of butyl rubber.

Named to new position in Hooker Chemical's phosphorus division is **R. George Hartig.** He is supervisor of process design, with headquarters at Jeffersonville, Indiana.

In other changes at Hooker, **Alex Katona** was transferred into product development at the company's new Research Center at Niagara Falls, New York.

Robert S. Forsyth moves up into the position of senior development chemist at National Starch and Chemical. Forsyth's work is with the adhesive technical development group.

John L. Patterson steps into the job of assistant manager, film manufacturing at Eastman Kodak, Rochester, New York. He succeeds **Richard M. Wilson,** who became manager of film manufacturing.

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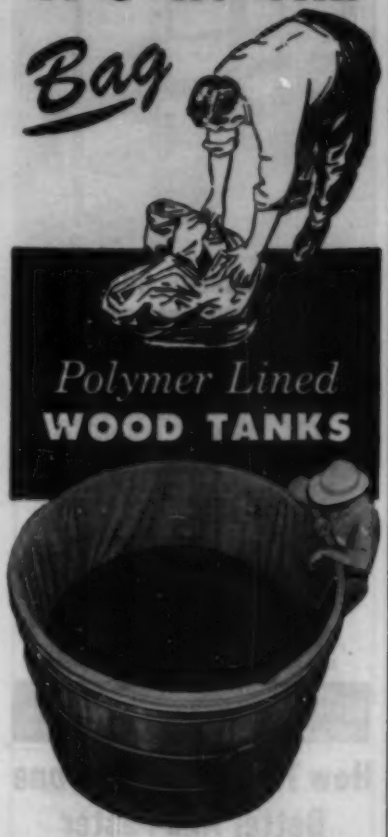

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people

John R. Thomas appointed manager of Globe-Union's Battery Engineering Department. He comes to the firm from Dewey & Almy (W. R. Grace).

W. Paul Moeller has joined AviSun as manager, special projects. He was previously manager of the Plastics Division, Celanese Corp. Moeller, in addition to twenty years association with Celanese, also taught at several engineering schools.

people in marketing

I. H. Munro has been elected vice president, marketing, at Allied Chemical, and **Irb H. Fooshee** vice president, manufacturing. Munro is president of Solvay Process Division; Fooshee is in charge of General Chemical Division. Both men continue to head their respective Divisions.

At Solvay Process, **Robert E. James** moves to the Moundsville, West Va, plant as manager. **Edward J. Walsh** replaces him as manager at the Baltimore Works.

Richard F. Protiva appointed manager, market development at Heil Process Equipment. Protiva joined the Cleveland firm in 1940 as sales engineer, and has been eastern sales manager since 1957. **Robert E. Scheel** moves into the position of manager, national branch sales.

Changes in Dow Corning sales office bring **Max H. Leavenworth** into the post of manager, Cleveland office. **Edwin Haire** will succeed him as manager, Southwestern branch in Dallas, Texas.

Albert Gnesin appointed east coast regional sales manager at Delhi-Taylor Oil, Chemical Division. Gnesin was formerly with Davison Chemical as district sales manager, and as engineer in the Technical Service Department. His offices will be in New York City.

Edwin T. Richard joined the Marketing Department of Monsanto's Inorganic Chemicals Division. He is manager, marketing research.

continued on page 182

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people in marketing

from page 181

Robert E. Deatz moves into the newly created position of manager, product planning at Girdler Process Equipment Division, Chemetron. He will be responsible for research and planning aimed at market expansion and development of new product lines.

NECROLOGY

William Spencer Bowen, 73, founder and honorary director of Bowen Engineering, Inc. Bowen served actively on the board of the company until 1958, when he became honorary director. He retired from the post of director of research in 1951. Bowen had over 60 patents, most of them in the field of spray drying. In 1955, he presented a paper, Bowen Solar Energy Mechanism, before a meeting of the Association of Applied Solar Energy. Bowen was an active member of ASME.

Harold S. Vance, 69. A member of the AEC since 1955, Vance was appointed to the commission by President Eisenhower for a term ending in June, 1960. His particular interest as a member of the commission was in industrial applications of atomic energy. Before appointment to the commission, Vance was chairman of the executive committee of the Studebaker-Packard Corp. He retired from the presidency of Studebaker in 1954.

Kenneth E. Kress, 36. He was supervisor of methods development in the analytical development laboratory at Firestone Tire & Rubber. Starting with the company in 1944, as a chemical engineer in the laboratory, Kress was named supervisor in 1953. He published several papers, including his latest, Photometric Determination of Zinc Oxide.

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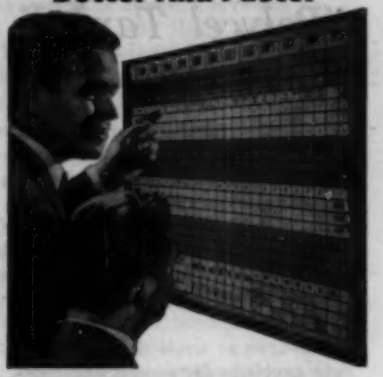

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(continued on page 186)

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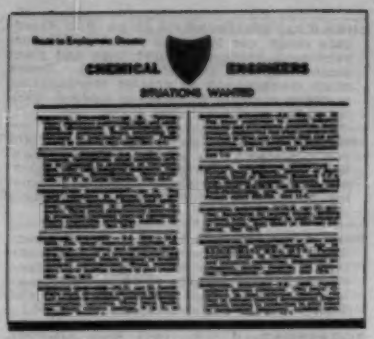

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SALES TRAINEE, Expert firm, chemical or mechanical graduate, 25-30, interested in sales in process equipment and basic machinery division of expert firm. Should have some information regarding process plant type of equipment. Salary $500 a month base, plus bonus and profit sharing. Location, San Francisco. S(P)-4661.

SALES ENGINEER, Industrial Chemical Equipment, 25-45, with sales experience in water, industrial treatment equipment and chemicals to industrial users, for manufacturer and distributor. Salary, $450-$600 a month plus incentive and expenses in developed territory. $10,000 potential. Headquarters, San Francisco Peninsula; work in Alameda County. S(P)-4673.

RESEARCH ENGINEER, Metallurgy, M.S. in chemical or metallurgical engineering or chemistry (not mining) or B.S. with exceptionally strong research experience; under 40. Must be interested in applying knowledge to solution of industrial problems rather than to fundamental research. Department conducts research and development on new processes and major process improvements in fields of mineral beneficiation, hydro-metallurgy and pyro-metallurgy. Salary commensurate with training and experience; liberal fringe benefits. Location, West. S(P)-4645R.

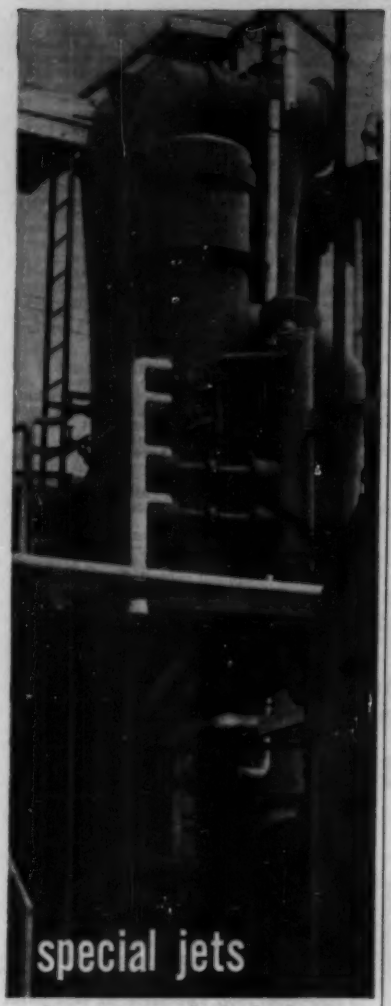
PRODUCTION CONTROL ENGINEER, Ceramics, chemical engineer or chemist, young. Oriented toward production and quality control; in highly mechanized refractory manufacturing company including raw materials, materials in process and finished product controlling. Salary, about $6000 a year. Location, San Francisco East Bay. S(P)-4636.

JUNIOR CHEMICAL ENGINEER, Refinery, graduate chemical, young, one or two years out of school, to enter into all-around engineering training program at level appropriate to experience; enter manufacturing department at refinery and actively participate in integrated program involving laboratory, process and operating departments; leads to staff, operation or process assignment located in San Francisco Bay area or Los Angeles area. Salary commensurate, with credit for experience. Pacific or Mountain States residents only. S(P)-4634R.

SALES ENGINEER, Chemical, Food Process Equipment, chemical graduate preferred, to 40, experienced in contacting engineering companies and users to provide technical information and sell major items of equipment and machinery for chemical and food industries (evaporators, sprayers, dryers, pulverizers and dust collectors, pumps, belt-scales, centrifugals, screens, ice cream packagers), for manufacturer's agent. Car required. Local men only. Salary, $500-$700 a month, plus possible bonus. Location, northern California. S(P)-4616.

SALES ENGINEER, Instrumentation, chemical, electrical or mechanical graduate, 27-35, with three to five years' experience in instrumentation (engineering, sales or industrial process plant). Preferably with some sales experience. Will train three months in eastern factory. Must pass aptitude test. Salary depends on experience and test rating. Sell to O.E.M. and industrial users a full line of instruments (electric, tronic, pneumatic or mechanical) for recording, control or actuators on temperature, pressure low. For manufacturer's branch office. Salary, $500 a month up, depending on experience. Local men only. Location, San Francisco East Bay. S(P)-4341.

SALES, Instruments, electrical, chemical or mechanical, to 30, with two years' experience after graduation to sell instruments (recording actuating, direct reading) for temperature, pressure flow, to industrial, educational or laboratory users; also to handle digital computer contacts. For manufacturer's district sales office. Salary, $122 a week up, plus car allowance and expenses. Location, San Francisco. S(P)-4608R.



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industrial news

A metallurgical research center to speed development of high temperature metals for jet engines, rockets and missiles, atomic power generators, and other advanced design hardware, will be built at Du Pont's Baltimore plant. Initially, the new unit will concentrate on large scale testing of titanium metal, and pure niobium metal and niobium alloys.

A European sales office just opened by B. F. Goodrich Chemical is located in The Hague, Holland. In addition to serving as the European sales headquarters for plastic materials, special purpose rubber and general chemicals, the Holland office will also supply technical service information.

The first ferrous sulfate decomposition plant in the United Kingdom just went on stream at the Grimsby Works of British Titan Products Co. Ltd. At the plant, which produces SO_2 gas for sulfuric acid manufacture, the by-product ferrous sulfate is decomposed with coal in fluidized bed roasters. The product SO_2 gas is converted to SO_3 for sulfuric acid production in one of the existing converters. Iron is recovered as a relatively pure mixture of iron oxides usable by the steel industry. Chemical Construction (G.B.) Ltd. (Chemico) designed and built the plant, using Dorr Oliver Fluo Solid Reactors.

Increased interest in methacrylate based products has brought about a 40 percent expansion in methyl methacrylate monomer production at Du-pont. The Belle, West Va. plant addition, when complete, will be also used to support markets for Lucite 147 and Lucite acrylic sirup.

An experimental sea water distillation plant, capacity 100,000 gallons a day, now being erected by Southern California Edison, will be located next to the company's Mandalay Beach Steam Station near Oxnard, California. The research and development unit will work on the problem of producing potable water commercially, competitive to that in areas of higher than average water cost. Design and fabrication is by Cleaver-Brooks.

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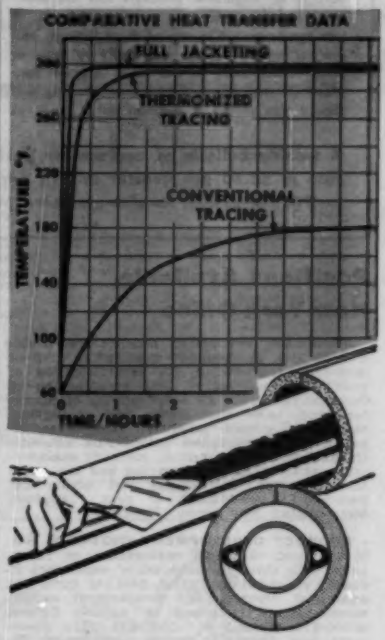

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News and Notes of A.I.Ch.E.

Get out the vote—Election ballots listing the candidates shown on pages 114 and 115 of the August issue* will be sent to all Members and Associate Members of the A.I.Ch.E. As we did last year, we are using an IBM card as the ballot, and we hope that members will exercise care in not mutilating the card, so that it will easily pass through the tabulating machinery. The Tellers' Committee will be composed of R. J. Bechtel, J. W. Colton, Brian Dallas, J. D. Stett, and J. F. Skelly.

Ground breaking—As this is being written, the five Founder Societies are making plans for Herbert Hoover to turn over the first spadeful of earth in the excavation for the new United Engineering Center. This will occur on October first. Occupancy of the new building is expected to take place in July of 1961—provided, of course, that the money is there. As readers of this column know, the A.I.Ch.E. has reached its quota and will this fall announce a campaign to augment this amount through reconstituted drives in the Local Sections that have not reached their quotas, plus efforts to reach members who have not given and new members added since the campaign began. As far as financing is concerned, the total Member-Giving Campaign has obtained $2,616,000 out of the goal of $3,000,000. The Industry Campaign has reached $4,300,000 out of a goal of $5,000,000.

These, plus additional money from Greater New York, bring the total subscriptions to date to $7,170,000.

What will the building cost? The building cost will be approximately $8,000,000; the land, services, and fees will add about another $3,500,000; and so the total to be spent on the new building will be roughly $11,500,000. When the sale of the present building is realized and the amortization funds of U.E.T. are included, needed funding should be on the order of $2,500,000 more than we have at present. The leaders in the United Engineering Trustees, confident that it will be possible to raise this amount, have given the go-ahead sign for the construction of this new home. Congratulations are again extended to all the members who have pitched in to make it a reality.

As this goes to press, another nominee for Director has been added to the ballot.

New Membership Chairman — Irv Leibson, who has been Matt Jones's lieutenant for the Southern Division, was appointed Chairman of the National Membership Committee by the Executive Committee last month. Matt Jones, who has done a fine job for a year and a half, had to give up his duties when he was transferred by Monsanto to become Plant Manager at their Port Plastics Plant in Addyston, Ohio.

The membership race between the North and South finds General Sam West of the Northern Division way out in front. All indications are that the sections will have a very strong closing drive for this year to send the new membership total ahead of last year. Every member of A.I.Ch.E. ought to cooperate with the local A.I.Ch.E. membership chairman; a little aid and encouragement is a wonderful thing for these men who month after month present the case of membership in the professional society to chemical engineers who have not yet joined.

Local Section activities—The Local Sections have had an extremely fine year, and from all indications the coming season will be just as active and just as important. Bill Johnston of the Indianapolis Section wrote me about the activities during the past year and noted that despite the loss of an operating unit within their territory which took out a number of chemical engineers, membership activity continued and the group increased its membership by 50 per cent. Indianapolis is a small section of recent admission, but it has inaugurated a program of guidance to high school students and presented to them a forum on chemical engineering.

George Gibbs, Chairman of the South Texas Section of A.I.Ch.E., wrote me a pleasant note that included a fine idea. He asked for ten copies of the booklet on professional standards and suggested that we mention the booklet in the News & Notes columns once a year. It is *the* best statement of the professional responsibilities of engineers and the responsibilities of employers of engineers that I have ever seen. The work of an Institute committee, the pamphlet has been reprinted several times; up to now we have distributed well over 30,000 copies. Any Local Section chairman or any member who wishes a copy need only drop us a card. It is, I repeat, an important document that spells out clearly the responsibilities of chemical engineers.

The Savannah River Section, which is under the direction of D. S. Webster, has issued an inexpensive but nonetheless important directory of the section, which covers the history of the section and discusses its activities; for instance, the members conducted a science fair for teachers and students in grade and high schools in eight counties of South Carolina and

ten counties in Georgia and also presented slide rules and drawing sets to the best science and mathematics students in the local high school. This is a vital program, of which chemical engineers may well be proud.

The South Texas Section also turned out a bound directory, and the Chicago Section turns out an Annual Report which includes reports from each one of its committees.

New dues bills—This year the IBM system will really be put into operation for bookkeeping purposes. Under the direction of the Manager of the IBM Department, Brian Dallas, we expect to bill members at the same time for A.I.Ch.E. dues, for divisional dues, for the *A.I.Ch.E. Journal*, etc. To this end we are starting a new system of membership numbers, which will refer not to the length of time a man has been a member but to bookkeeping procedures and which will enable us to bill and to credit payments more accurately. F.J.V.A.

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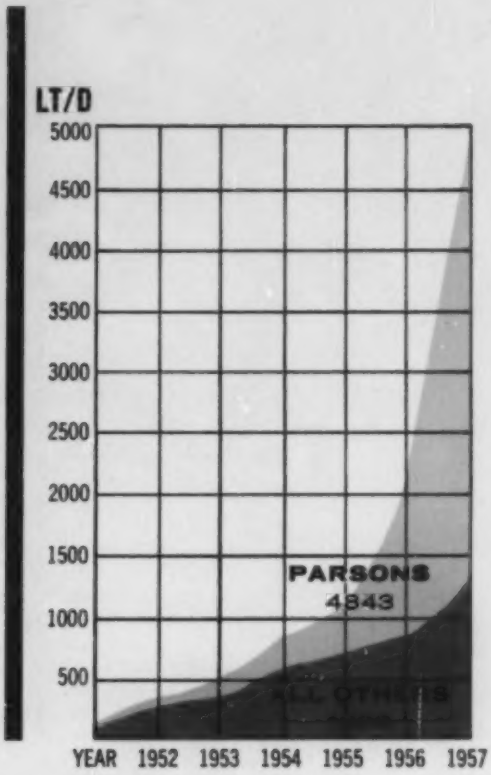

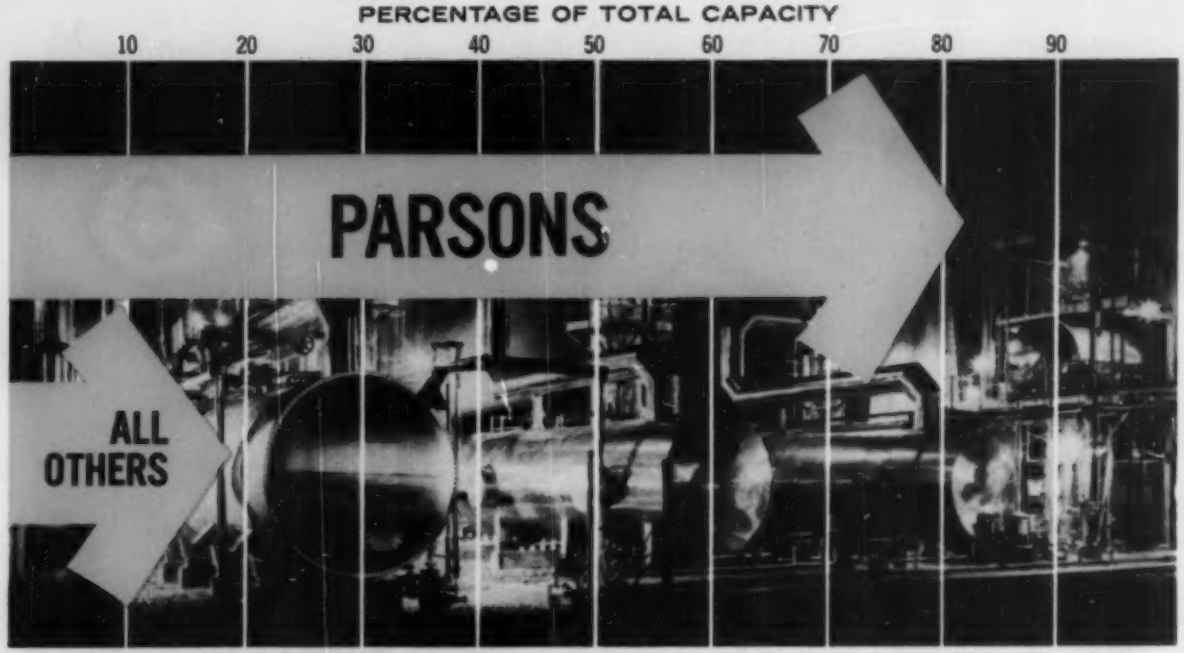

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Among other useful indications, this heat-transfer correlation shows that you get best values of *h* with impeller flow as large as practicable, and with tube diameter small as practicable. It helps to settle the problem of where to locate baffles. It throws new light on the relative efficiencies of helical coils and vertical tubes for heating or cooling.

To pin down accurate values of *h* in this investigation, some elaborate methods were employed. Thermocouples embedded in the tube wall made possible direct measurement of temperatures across the fluid film. Continuous recording of temperatures in more than 20 carefully selected positions in the tank gave a valid calculation of average system temperatures. Duplicate runs, under steady-state and unsteady-state conditions, produced excellent agreement in results.

This is just one example of the lengths to which MIXCO research is prepared to go to help you process fluids efficiently. If you'd like a reprint of a four-page article describing this heat-transfer correlation, you can get it by writing to our Research Department.

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